Palaeolimnology as a Management Tool for Australian Aquatic Ecosystems

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Declaration

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Chapter 1: General Introduction - Palaeolimnology and aquatic ecosystem management

Chapter 2: Methods

General Introduction: Palaeolimnology and aquatic ecosystem management

1.1 Australian aquatic ecosystems

Many aquatic and terrestrial ecosystems in Australia have been extensively modified and in some cases degraded beyond rehabilitation since European settlement began over 200 years ago (Timms 2005). Land and water management practices, including the introduction of exotic species, in combination with Australia's variable rainfall and river flows, have led to many of the environmental problems faced by the country today, particularly the deteriorating water quality in many coastal and inland waters (Reid & Ogden 2006). With continued population growth and an increasing demand for resources, significant pressure is being placed on Australia's aquatic and terrestrial ecosystems (SoE 2006).

1.1.1 Deteriorating water quality

Declining water quality is a well documented problem in many parts of the world and Australia is no exception (de Jonge *et al.* 2002). Deteriorating water quality in Australian coastal and inland ecosystems stems from the land and water management practices employed since European settlement, particularly as a result of alterations to flow regimes (e.g. due to construction of dams and diversion of water for irrigation), extensive land clearing, increased nutrient inputs and the introduction of exotic species (Zann 1995). This has led to increased erosion, sedimentation and increased biological production in Australian coastal and inland waterways and a loss of habitat and biodiversity (SoE 2006). There are many examples of poor water quality in Australian aquatic ecosystems including problems associated with acidification, eutrophication and salinisation.

Eighty-five per cent of the Australian population is concentrated in settlements within 50 km of the coast, with the majority concentrated in eastern and southern Australia (Zann 1995). When European settlement began coastal waterways were often used to remove waste, under the assumption

that the waste would be flushed out to sea. In many cases these pollutants have remained and accumulated, and studies have demonstrated that even in permanently open estuaries, only about 30% of the material transported to them reaches the ocean on an annual basis (Davis & Kloop 2006).

A common problem is eutrophication, which is the process of nutrient enrichment and leads to increases in primary production, phytoplankton blooms and changes in species composition (Brodie 1995, Nixon 1995). Australian estuaries experience a range of different algal blooms consisting of cyanobacteria, diatoms, dinoflagellates and filamentous macroalgae (Davis & Kloop 2006). Eutrophication has caused significant changes in coastal nutrient cycling, water quality, biodiversity, fisheries and overall ecosystem health (Paerl *et al.* 2003). Nitrogen, phosphorus and to a lesser extent silica are considered to be the principal nutrients involved in eutrophication processes (Brodie 1995).

Eutrophication is one of the main problems facing coastal aquatic ecosystems in eastern and southern Australia (SoE 2006). However, relatively little research has been conducted on these coastal ecosystems in comparison to Northern Hemisphere sites. It is difficult to extrapolate data from the Northern Hemisphere to Australian sites because, while the basic processes leading to different environmental and water quality problems are the same, the relative importance of these processes and how they are influenced by climate and the physical and chemical characteristics of different ecosystems are not (Davis & Kloop 2006).

Traditional views of eutrophication have highlighted increased nutrient supply as the principle cause. It is now clear that in Australia, stratification and light penetration also play important roles (Davis & Kloop 2006). Diffuse sources of nutrients dominate nutrient input to Australian coastal lakes and estuaries and it is not only the quantity of nutrient loading that is important, but also the timing, location and nature of the loading. In dry periods, residence times are long, water velocity is low and particles settle out of the water column. During these periods there is likely to be greater light penetration into the water column and thus nutrient input can often lead to the development of algal blooms (Davis & Kloop 2006).

Phytoplankton blooms are a natural phenomenon in many of Australia's estuaries, lakes and rivers (Davis & Kloop 2006). However, it is not known whether European land and water management practices have influenced the spatial and temporal extent of algal blooms. There is no documentation of the state of the environment prior to European settlement or the extent of changes since. Few detailed water quality monitoring programmes have been undertaken and where they have, they have often been short term, sporadic, of limited scope and usually started after environmental problems have been identified (Smol 2008). This means that it is virtually impossible to establish what an ecosystem was like prior to human impacts based on historical documentation and water quality monitoring alone. It is widely acknowledged that present understanding of baseline conditions is necessary before appropriate management strategies and future plans can be developed (e.g. NLWRA 2000). However, this understanding is currently inadequate (SoE 2006).

1.1.2 Introduction of exotic species

Approximately 80% of the vertebrate and plant species in Australia are found nowhere else in the world (SoE 2006). Due to Australia's size, isolation, naturally fragmented landscapes and long term climate variability, many of Australia's ecological communities have a low resilience to external pressures, particularly introduced exotic species that can out-compete native flora and fauna (SoE 2006). Over 3000 non-native plant species have established populations in Australian territory and a number of feral animal species are listed as 'key threatening processes' in the 2006 State of the Environment Report (SoE 2006). These include cats, rabbits, rodents (on small islands), foxes, pigs and goats. These animals have contributed to the decline and extinction of a number of native plants and animals on the Australian continent, Tasmania and offshore islands (e.g. Macquarie Island). In particular, rabbits have caused significant damage and have had devastating effects on vegetation. Rabbits prevent the regeneration of plant species and impact bird and mammal populations by altering vegetation community structure and damaging soils (e.g. causing increased erosion, runoff and loss

of fertility; Robley *et al.* 2002). Feral cats acting alone or in association with other feral animals (e.g. rabbits and rodents) have contributed to the extinction of a number of species on islands (Robley *et al.* 2004). For example, predation by feral cats caused the extinction of the Macquarie ground parakeet (*Cyanoramphs erythrotis*) on World Heritage listed Macquarie Island (PWS 2007).

However, recognising change and determining the impact of feral animals and the implications for the future is difficult because of the lack of information about the condition of the environment prior to their introduction, the rate and extent of their impacts, or interactions with natural climate variability.

1.2 Management questions, challenges and priorities

A major management question today is how will ecosystems respond to increasing human pressures and climate change in the future (Davis & Kloop 2006). Aquatic environments change and respond to a multitude of factors, both natural and anthropogenic, over a range of temporal scales, but increasingly human activities are causing ecosystem changes that are well beyond the ranges of natural variability (IPCC 2007). Aquatic ecosystems cannot be treated as isolated systems. They are intimately linked to their catchments, the atmosphere and groundwater inflows (Smol 2008). In the past the economic value of aquatic ecosystems and their surrounding catchments has often taken precedence over their natural values and as a result management has been reactive rather than proactive (Woodroffe 2002).

It is widely recognised that successful management strategies depend on establishing realistic baselines and targets (Smol 1992, Battarbee 1999, European Union 2000, Duke *et al.* 2003, SoE 2006). This often requires understanding pre-impact conditions, identifying the nature and direction of subsequent changes and importantly, determining the range of natural variability. With these in place it is possible to assess the responses of biological systems to any remediation programmes (Vaalgamaa & Korhola 2004, Weckström *et al.* 2004, Battarbee *et al.* 2005). However, baseline data, historical documentation and water quality monitoring usually do not provide

an adequate temporal perspective (European Union 2000, Smol 2008, SoE 2006).

1.3 Palaeolimnological applications in aquatic ecosystem management

Palaeolimnology is the interpretation of past ecosystem conditions and processes based on lake sediment characteristics (Last & Smol 2001). Conservation palaeolimnology is based on the principle that understanding the past places the present into context and is therefore essential for successful future management (Willis & Birks 2006). The value of palaeolimnological approaches is increasingly being realised as managers of aquatic ecosystems acknowledge that, in most cases, instrumental data are inadequate for determining baseline conditions, which makes setting management and restoration strategies and targets difficult or impossible. In such cases, stratigraphic analyses of sediments provide the only way to investigate long term water quality trends (Brush & Davis 1984, Kauppila *et al.* 2005).

Key areas of management that palaeolimnological techniques can be applied to include establishing natural variability; determining baseline conditions for setting management targets; determining the causes of change and investigating ecosystem responses to remediation and restoration attempts.

1.3.1 Establishing natural variability

Understanding the range of natural variability, and in particular, being able to identify when human impacts exceed natural thresholds, is essential for maintaining good ecosystem health (Willis & Birks 2006). Much research into present day water quality degradation is carried out without establishing the range of natural variability on longer timescales (Battarbee *et al.* 2005). Palaeolimnological methods play a crucial role in this as they can identify the timing and progressive impact of different human activities and also provide a long enough temporal perspective to disentangle natural from anthropogenic-related changes (Willis & Birks 2006). Human impacts occur at a range of temporal scales. In many parts of the world, a time frame of 100-200 years

encompasses most modern environmental impacts and cause and effect over this period can be relatively clear (e.g. Birks *et al.* 1990, Taffs *et al.* 2008). In other locations, particularly in aquatic ecosystems with a long history of human settlement, impacts may have occurred over much longer time periods, which can make differentiating between natural and human-induced change more difficult (e.g. Fritz 1989, Anderson & Odgaard 1994, Bradshaw *et al.* 2006). This is particularly important for addressing perceived management problems such as eutrophication and algal blooms, which can occur naturally. For example, Reavie *et al.* (2000) used a palaeolimnological approach to determine the natural variability in nutrient concentrations in a series of lakes in British Columbia, Canada. They demonstrated that a number of lakes in the region are naturally eutrophic and thus rehabilitation and mitigation strategies to 'return' these lakes to oligotrophic conditions were unrealistic. Not understanding the range of natural variability may therefore result in inappropriate management strategies.

1.3.2 Determining baseline conditions for setting management targets

Managers increasingly want to return aquatic ecosystems to their 'natural' or 'pre-impact' state. To do this requires determination of baseline conditions, against which management targets can be set. However, identifying and establishing appropriate baseline conditions for aquatic ecosystem management is a major challenge as it requires consideration of the past and present stressors on an aquatic ecosystem and its surrounding catchment. In most cases the information to determine these baseline conditions is not available without using a palaeolimnological approach, as nearby undisturbed 'reference sites' do not always exist. For example, Bennion *et al.* (2004) used a palaeolimnological approach at 26 Scottish freshwater lochs to determine baseline nutrient (pre-1850 AD) conditions and demonstrated that the phosphate concentrations in 19 out of 26 lochs had increased since pre-1850 AD.

Many management strategies define their baselines in terms of 'natural' or 'pre-impact' conditions and aim to restore sites to this status (e.g. European Union 2000, NLWRA 2000). However, definitions of 'natural' and

'pre-impact' are subject to different interpretations depending on cultural and social perspectives, and public and institutional memory does not often extend far enough back in time to be able to identify realistic baselines and the potential of ecosystems to recover (Willis & Birks 2006, Köster *et al.* 2007). For example, Köster *et al.* (2007) used a multiproxy palaeolimnological approach to determine natural baseline conditions and investigate the recovery of a severely degraded river-estuary in Maine, USA. This information was used to demonstrate that little environmental recovery occurred with the implementation of environmental legislation in the 1960s and 1970s and that the 'baseline' condition of the system was very different to peoples' perceptions.

In many instances, ecosystems may have been modified to such an extent that aiming for 'natural' or 'pre-impact' conditions is unrealistic as land clearing has irrevocably changed most landscapes. In such cases, determining which ecosystem state is the most suitable to aim for, needs to be based on an understanding of the degree and type of human impact and an acceptance of the ongoing role humans will play in ecosystem processes (Hunter 1996). It is also important to consider the implications of additional human interference in attempts to achieve a 'natural' state through proactive management (Kauppila *et al.* 2005).

1.3.3 Determining the causes of change and investigating ecosystem responses to remediation and restoration attempts

Palaeolimnological studies can be used to determine potential causes of change and identify the early warning signs of changes not necessarily detected by routine water quality monitoring. For example, in the 1980s when the reason for widespread lake acidification in Northern Europe was debated, a palaeolimnological approach was used to assess the influences of land use and catchment vegetation (Battarbee 1990, Renberg & Battarbee 1990) and the influence of fossil fuel burning, which was found to be the overall driver (Flower *et al.* 1994). In another study, Merilaeinen *et al.* (2000) used a palaeolimnological approach to show that restorative efforts to address eutrophication in a lake were unsuccessful due to nutrient loading via diffuse

sources. Point source nutrient loading is often monitored and strictly regulated, but little is generally known about the amounts and impacts of diffuse sources. In this case, restorative work did not lead to biological recovery because of an enormous increase in diffuse nutrient loading from agriculture, forestry and lake level lowering, despite focused efforts to reduce point source inputs. Similarly, Gikas *et al.* (2006) used a palaeolimnological approach to demonstrate that failure to reduce eutrophication in a lake was due to internal supply of phosphorus from sediments, while Cooper and Brush (1993) demonstrated that European settlement and land use change were responsible for eutrophication in Chesapeake Bay, USA.

The chances of successful restoration are limited by the difficulty of changing long established land use and catchment management practices (Battarbee *et al.* 2005). Palaeolimnological studies can be used to determine the consequences of land use change on water quality and consequently aid managers in assessing options and educating landowners about the implications of their land management practices.

1.4 Palaeolimnological methods

Palaeolimnologists have a number of valuable tools (Table 1.1). Of the biological indicators available, diatoms are the most widely used, particularly in nutrient-based research (Denys 2003, Dixit *et al.* 1992).

1.4.1 Diatoms

Diatoms are unicellular algae with a siliceous cell wall that preserves well in most sediments. Diatoms colonise all types of aquatic habitats from freshwater to marine environments, in all regions of the world (Anderson & Vos 1992). They are dominant components of benthic and planktonic communities, occurring in high numbers with rapid reproductive rates, high species diversity and niche specificity (Denys & de Wolf 1999).

Many diatom taxa have distinct ecological requirements and limited tolerances to different water quality parameters and are therefore highly sensitive to changes in their environment (Reid *et al.* 1995). Diatoms can be

excellent indicators of change over a wide range of environmental variables including nutrient levels, salinity, pH, temperature, light availability, tidal exposure and tidal zonation (Stoemer & Smol 1999).

Table 1.1: Common palaeolimnological techniques used to develop environmental histories and the different environmental issues that can be addressed with them.

Technique	Environmental issue	Example
Physical and geochemical		
• Isotopes	sources of input and evaporation and precipitation balance	Byrne *et al.* 2001, Ellegaard *et al.* 2006
• Persistent organic pollutants	local and atmospheric organic pollution	Merilainen *et al.* 2003, Rose *et al.* 2004
• Spheroidal carbonaceous fly ash particles	atmospheric pollution	Rose *et al.* 2004, Kamenik *et al.* 2005, Chirinos *et al.* 2006
• Trace metals	local and atmospheric pollution	Boyle *et al.* 2004, Bouezmarni & Wollast 2005, Salonen *et al.* 2006
Biological		
• Chrysophytes	water quality	Paterson *et al.* 2004, Garcia-Rodriquez 2006
• Cladocera	water quality, lake depth	Johansson *et al.* 2005, Sweetman & Smol 2007, Szeroczynska *et al.* 2007
• Diatoms	water quality	Clarke *et al.* 2003, Ryves *et al.* 2004, Weckström 2006, Saunders *et al.* 2007, Taffs *et al.* 2008
• Formaminifera	sea level	Gehrels *et al.* 2006, Horton *et al.* 2006
• Macro invertebrates	water quality	Dahl & Johnson 2006
• Ostracods	water quality	Mezquita *et al.* 2005
• Pigments	palaeoproductivity	Chmura *et al.* 2004, Ellegaard *et al.* 2006, Hodgson *et al.* 2006a
• Pollen	vegetation change, land use change	Byrne *et al.* 2001, McGlone *et al.* 2000
• Testate amoebae	water quality	Gearey & Caseldine 2006, Langdon & Barber 2005

Several diatom taxa are endemic to different regions of the Southern Hemisphere (Vyverman *et al.* 2007). Tyler (1992) suggested that a significant number of diatom taxa in Tasmanian inland lakes may be endemic, while John (1983) described several new species in Western Australia. Le Cohu and Van de Vijver (2002), Van de Vijver and McBride (2006) and Van de Vijver *et al.* (2002a, 2005, 2006) identified several new species from the sub-Antarctic, while Gibson *et al.* (2006) identified several new species from the Antarctic. Recent coastal studies (e.g. McMinn *et al.* 2003, Lane 2004, Haynes *et al.* 2007, Saunders *et al.* 2007, Taffs *et al.* 2008) have shown that some diatom taxa in eastern and southern mainland Australia and Tasmania are also found in the Northern Hemisphere. However, using the ecological preferences of diatoms determined from outside a study region can be problematic. Taylor *et al.* (2007) demonstrated that while many diatom taxa in South Africa were cosmopolitan with similar ecological tolerances to European taxa, several possibly endemic taxa were recorded. They concluded that for management purposes, the application of diatom-based water quality indices needed to be based on locally derived data.

1.4.2 Quantitative palaeolimnological techniques: transfer functions

Quantitative data and assessments are generally required by environmental managers. Until the 1970s water quality monitoring that included a biological component mainly depended on identifying the presence or absence of indicator species (i.e. key species that are known to occur in certain environmental conditions). However, this approach has the fundamental limitation that the indicator species taken to be indicative of a certain environmental problem (e.g. pollution) may also occur in sites that do not have the problem. While qualitative information regarding the disappearance or appearance of certain taxa known to be characteristic of certain environmental conditions is valuable, quantitative information about species ecological preferences is necessary for characterising and assessing aquatic ecosystems.

The development of quantitative methods to relate diatom assemblages to water chemistry variables through diatom-based transfer functions, has

become a common tool in palaeolimnological studies: both to characterise current conditions at a site and to investigate past environmental changes and causes of change. Transfer functions define the mathematical relationship between diatom species assemblages and environmental variables (Jones & Juggins 1995).

The development of transfer functions consists of two steps. The first step involves the development of a reference dataset, which is a matrix consisting of diatom species abundances (usually as a relative percentage of the total number of valves counted) and modern water quality information (e.g. nutrient concentrations, salinity, temperature and pH) in a wide range of sites.

The reference dataset should ideally include sites with a wide range of the environmental variables to be reconstructed and a wide range of diatom species. This is to ensure that the species assemblages found in the sediment core samples are also represented in the reference dataset (Martin 2001).

At each site, water quality data is recorded and a surface sediment sample is collected. Surface sediment samples usually contain an integrated flora representative of average conditions at a site. In contrast, water chemistry measurements provide a snapshot of conditions at the time of sampling and are consequently subject to 'spikes' or extreme events (Hall & Smol 1992). As a result, the surface sediment samples should be collected at the end of the water quality sampling period (e.g. 1 year) to ensure that the diatom assemblages within the surface sediment samples are representative of the water quality conditions measured during the study period (Bennion & Smith 2000).

The diatom species preserved in the surface sediment samples are identified and counted in order to investigate the relationship between the different diatom assemblages and the measured environmental variables using multivariate statistical techniques. In order to develop a transfer function the environmental variable of interest needs to explain a significant part of the total variance in the diatom species assemblages, independent of other environmental variables (Battarbee *et al.* 2001).

The development and application of transfer functions is based on a number of assumptions (Birks *et al.* 1990):

(i) Modern (surface sediment) diatom assemblages are related to the physical and chemical environment from which they were sampled;

(ii) Fossil diatom assemblages are related to the physical and chemical environment in which they were deposited;

(iii) Past physical and chemical environments have remained within the range of the reference dataset;

(iv) Species responses to their environment have remained unchanged over time; and

(v) Relationships between the diatom assemblages and water chemistry variables under investigation are non-linear.

If these assumptions are not met, reconstructing past environmental conditions is not reliable.

The weighted averaging regression and calibration transfer function technique is currently the most widely used (Battarbee *et al.* 2001). This approach is based on the principle that at a given value of an environmental variable, taxa that have an optimum nearest to that value will have their greatest abundance and will follow a Gaussian unimodal response curve (Figure 1.1; Birks *et al.* 1990).

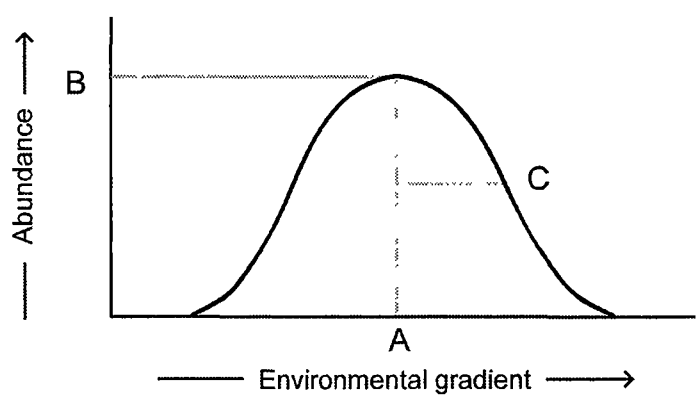


Figure 1.1: The ecological response model of species, based on the Gaussian unimodal response curve. Where A = optimum, B = maximum, C = tolerance (1 standard deviation). Figure modified from Battarbee *et al.* (2001).

Weighted averaging regression involves modelling the relationship between diatoms identified in the reference dataset and the measured

environmental variables. The relative abundance of each species is weighted by the values of the environmental variable to which it responds. This provides an estimate of a species' optimum and tolerance for that environmental variable (Battarbee *et al.* 2001). Weighted averaging calibration involves using the modelled responses (i.e. species' optimum and tolerance) from weighted averaging regression to infer environmental conditions from the composition of fossil diatom assemblages (Birks *et al.* 1990).

The predictive ability of transfer functions may be assessed by examining the relationship between measured and inferred values of environmental variables. However, calculating the correlation (r^2) and root mean squared error (RMSE) on the basis of the reference dataset alone may be misleading as the same data is being used to generate and evaluate the model (Battarbee *et al.* 2001). To avoid this problem, it is more appropriate to use a cross validation technique such as jackknifing. In jackknifing, one sample is excluded from the original dataset and the inferred value of the environmental variable for that sample is based on the optima and tolerances of the taxa in the remaining samples of the reference dataset (Birks *et al.* 1990).

There are a number of different weighted averaging approaches that can be used when developing transfer functions. Birks *et al.* (1990) recommended simple weighted averaging as the simplest and most reliable environmental reconstruction procedure. Some authors (e.g. Bradshaw & Anderson 2001) have found that weighted averaging with tolerance downweighting provides the best transfer function performance, while others (e.g. Bennion *et al.* 1996) have found that weighted averaging-partial least squares (WAPLS) provided the best. Simple weighted averaging works best with noisy data, while WAPLS tends to outperform simple weighted averaging with low noise data (Birks 1998). Additionally, if there is a strong secondary gradient in the data (which is common in nutrient-based studies, particularly in coastal studies where salinity is usually an independent variable influencing diatom composition as well as nutrients), WAPLS tends to perform better than simple weighted averaging (Birks 1998).

Diatom-based transfer functions have been developed to reconstruct changes in various environmental variables including nutrients (e.g. Bennion

1994, Bennion *et al.* 1996, Martin 2001, Garcia-Rodriguez *et al.* 2002, Tibby 2004, Weckström *et al.* 2004), salinity (e.g. Fritz *et al.* 1991, Roberts & McMinn 1998, Gell 1997, Ryves *et al.* 2001, Taffs 2001, Clarke *et al.* 2003, Saunders *et al.* 2007), pH (e.g. Birks *et al.* 1990, Bennion 1994, Tibby *et al.* 2003, Taffs *et al.* 2008), chlorophyll *a* (e.g. Jones & Juggins 1995), and altitude and temperature (e.g. Bigler & Hall 2003, Wolfe 2003, Gremmen *et al.* 2007). Most palaeolimnological studies have focused on lake ecosystems and have been conducted in the Northern Hemisphere. However, the number of studies in the Southern Hemisphere has increased in recent years.

1.5 Potential limitations

While palaeolimnological techniques are potentially valuable and provide a powerful set of management tools, they are not without limitations. Natural archives are subject to 'filtering' of past environmental information through physical and biological processes (Swetnam *et al.* 1999). Interpretation of palaeolimnological data relies on the assumption that the relationships between physical and biological processes are the same as in the past (Birks 1998). Sediment record integrity may be disturbed by bioturbation and consequently establishing a good chronology can be difficult (e.g. Crusius *et al.* 2004, Lomax *et al.* 2007, Bateman *et al.* 2007). Poor preservation of microfossils (e.g. Ryves *et al.* 2001, Lent & Lyons 2001), 'no analogue' situations (i.e. where the modern reference dataset does not capture down-core biological- and physical-environment interactions, Swetnam *et al.* 1999), and identifying sediment origin (e.g. Vos & de Wolf 1993) all place limitations upon the use of palaeolimnological data. Ideally, palaeolimnological studies using multiple indicators (e.g. Chmura *et al.* 2006, Köster *et al.* 2007, Reavie & Baratono 2007) and multiple cores (e.g. Haynes *et al.* 2007, Fluin *et al.* 2007) are recommended as they can reduce uncertainties or at least provide additional information to address them if they do occur.

1.6 Thesis Aims

This Thesis applies a palaeolimnological approach in two contrasting Australian aquatic environments, each with different problems and human impact histories. The sites were chosen to reflect two different key environmental issues currently facing Australia and to demonstrate the wide range of aquatic environments to which palaeolimnological techniques can be applied.

The first site was Lake King, southeast mainland Australia (Figure 1.2). Lake King is one of a series of lakes that form the Gippsland Lakes, the largest estuarine system in Australia. The Gippsland Lakes have high conservation value, but human activities since European settlement began in the 1840s, in particular the construction of a permanent entrance connecting the lakes to the sea in 1889, have led to a series of environmental issues primarily resulting in declining water quality and nuisance algal blooms. Improving the water quality of the Gippsland Lakes is currently a focus of management efforts, but little is known about the pre-permanent entrance state of Lake King, which makes identifying baselines and targets difficult. Consequently, a palaeolimnological approach to determine the pre-permanent entrance status of Lake King has a valuable contribution to make to future management.

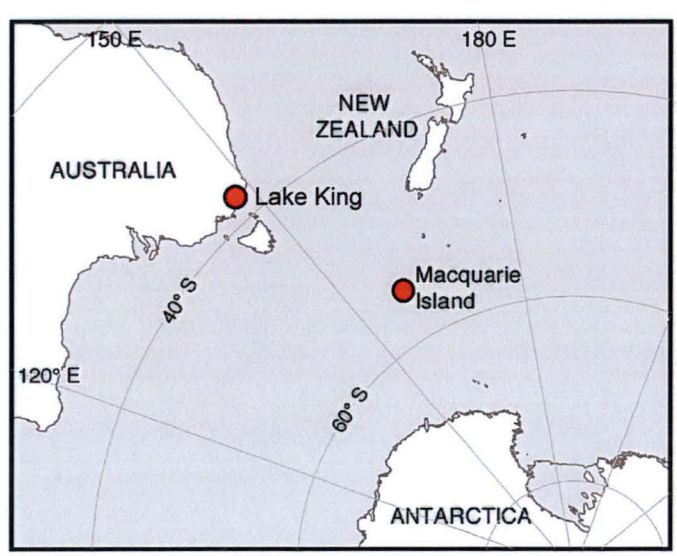


Figure 1.2: Location of study sites

The second site was Emerald Lake, sub-Antarctic Macquarie Island (Figure 1.2). Macquarie Island has experienced extensive feral animal impacts since humans arrived in 1810. In particular, widespread destruction of vegetation and landslides have occurred. A rabbit and rodent eradication programme is currently being planned (PWS 2007), but little is known about the environment of Macquarie Island prior to 1810. Successful restoration and rehabilitation of Macquarie Island requires an understanding of pre-impact conditions and the role of natural climate variability and the implications of future climate change in order to assess the response of the island once the feral animals have been removed. Consequently, a palaeolimnological approach provides an opportunity to determine the pre-impact conditions and past natural climate variability.

The specific Aims of this Thesis are to:

(i) Use a palaeolimnological approach to assess human impacts and ecological changes that occurred since European settlement in southeast Australian estuaries and to determine reference conditions for developing management strategies;

(ii) Use a palaeolimnological approach to assess recent environmental changes on World Heritage listed sub-Antarctic Macquarie Island in terms of human occupation, the introduction of feral animals and climate variability and the implications of these changes for future management strategies.

1.7 Thesis structure

This Thesis consists of seven Chapters. Chapter 1 (this Chapter) provides a general introduction and background to palaeolimnology and its potential applications. Chapter 2 describes the Methods used. The Results section is divided into four Chapters (Chapters 3-6). Each Chapter has its own Introduction and Discussion of the results.

Chapters 3 and 4 address Aim (i) above. Chapter 3 outlines the development of the Tasmanian and Victorian diatom reference datasets and transfer functions. Chapter 4 describes the application of the Victorian diatom

reference dataset and transfer functions to reconstruct the environmental history of Lake King, southeast Australia, from the mid 19th century to present.

Chapters 5 and 6 address Aim (ii) above. Chapter 5 outlines the development of the Macquarie Island diatom reference dataset and transfer functions. Chapter 6 describes the application of the Macquarie Island diatom reference dataset and transfer functions to reconstruct the environmental history of Emerald Lake during the Holocene.

Chapter 7 is a General Discussion and Summary of the Thesis including an evaluation of the role of palaeolimnology in future Australian ecosystem management. The Appendices include all diatom taxonomy and raw data, together with copies of published and submitted papers that are based on the work presented in this Thesis.

The overall objective of this Thesis is to demonstrate the value of palaeolimnology, using diatom transfer functions, in identifying the impacts and consequences of human activities and in developing future management strategies.

Methods

2.1 Dataset sample collection

Forty sites from 23 coastal lakes and lagoons in Tasmania, 45 sites from 13 coastal lakes and lagoons in Victoria (Figure 2.1) and 58 sites from 50 coastal and inland lakes on Macquarie Island (Figure 2.2) were sampled to develop three reference datasets incorporating modern surface sediment diatom assemblages and water quality measurements. Sites in Victoria and Tasmania were visited twice during the period of data collection (August-September 2004 and February-March 2005) in order to capture some of the seasonal variation in limnology. Sites on Macquarie Island were sampled once from February-April 2006.

Sites in Tasmania and Victoria incorporated a wide variety of human impacts and ranged from heavily affected to little impacted. The number of samples taken from each water body was variable (range 1 to 14 sites), depending on the size of the water body and accessibility and were chosen to include sites associated with specific nutrient inputs and human impacts. The sites on Macquarie Island include most ponds and lakes. The largest four lakes were sampled at two locations (at the western and eastern sides) to try and account for spatial variability in nutrients and conductivity.

At each site, surface sediment samples and water chemistry data were collected. Surface sediment samples (top 1 cm) were collected from approximately 1 m water depth using a hand-operated gravity corer. The majority of surface sediment samples were collected at the end of the sampling period to ensure that the diatom species identified corresponded with the normal range of water chemistry experienced during the sampling period. Conductivity, dissolved oxygen, pH, salinity, temperature and turbidity were measured using a Horiba U-10 Water Quality Checker in Tasmania and Victoria, and a Hydrolab Datasonde 4a on Macquarie Island. Duplicate water samples were collected for soluble reactive phosphate (referred to as phosphate), nitrate/nitrite and silicate analyses. Sample tubes were rinsed several times in lake water at each site prior to collection. Samples were frozen and analysed using Lachat Instrument (Injection Flow Analyser) following the Quikchem Methods 31-115-01-1-I (phosphate), 31-107-04-1-A (nitrate/nitrite) and 31-114-27-1-D (silicate) at the Commonwealth

Scientific and Industrial Research Organisation Marine and Atmospheric Laboratories, Hobart, as soon as possible after collection.

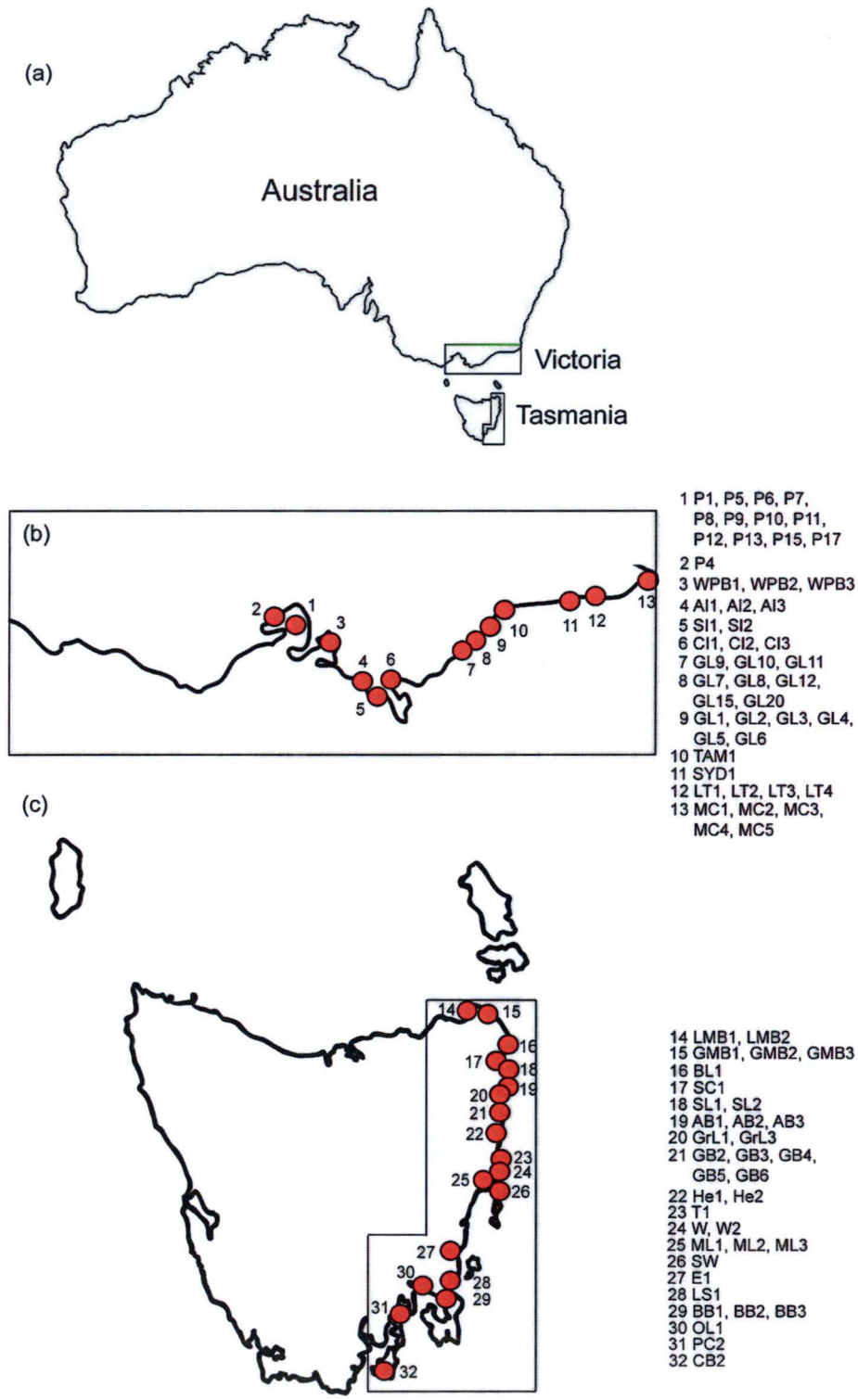


Figure 2.1: (a) Location of study regions; (b) location of coastal lagoons and estuaries sampled in the Victorian dataset; (c) location of coastal lagoons and estuaries sampled in the Tasmanian dataset with specific sites numbered. See Appendix 1 for specific locations of sampling sites and site abbreviations in full.

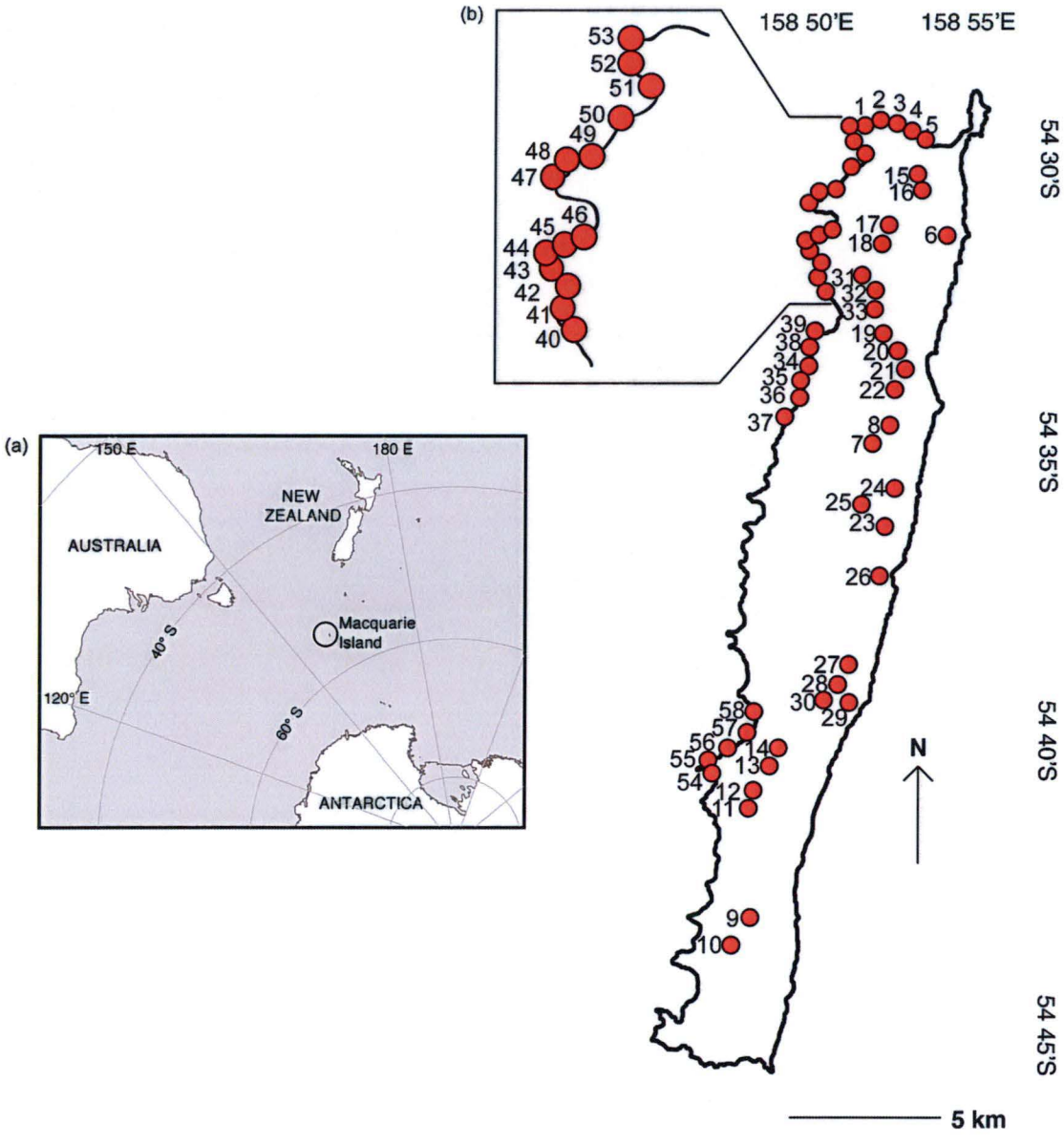


Figure 2.2: (a) Geographical location of Macquarie Island and (b) location of sampling sites indicated by the red dots.

2.2 Sediment core collection

All sediment cores were collected using a gravity corer.

2.2.1 Lake King, Gippsland Lakes, Victoria

A 120 cm sediment core was collected from Lake King, Gippsland Lakes, from a water depth of 7 m in September 2005 (Figure 2.3). The core was sub-sampled on-site at 0.5 cm intervals from 0-50 cm and 1 cm intervals from 50-120 cm.

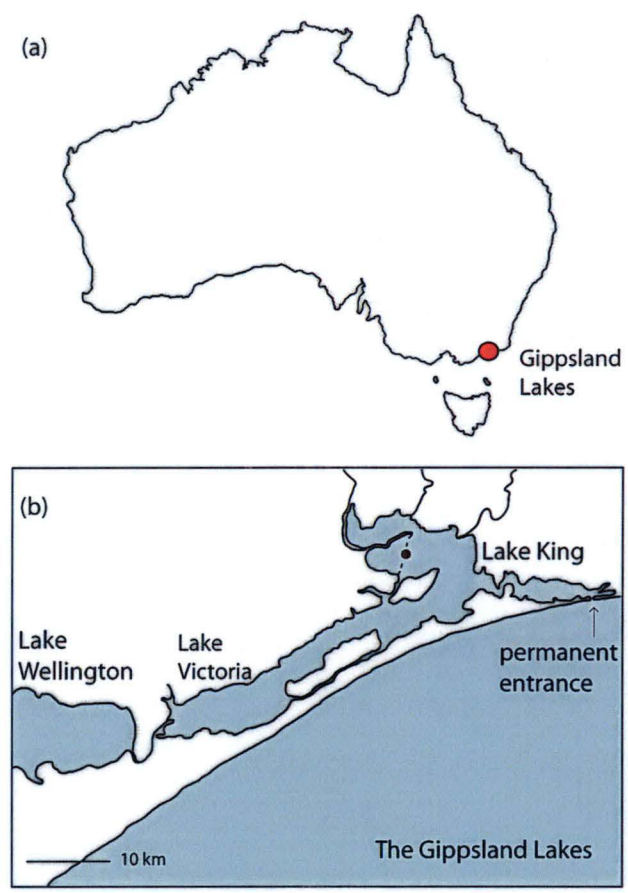


Figure 2.3: (a) Location of the Gippsland Lakes, Victoria; and (b) location of Lake King, core site (•) and transect (---).

Due to the size of Lake King (92 km^2), a transect of surface sediments and surface water chemistry was also conducted to try and capture some of the spatial variability within the lake and allow transfer functions tailored to Lake King to be

applied (Figure 2.3). Surface sediments were collected with an Ekman Grab. Samples were stored at 4 °C until analysis.

2.2.3 Emerald Lake, sub-Antarctic Macquarie Island

A 50.5 cm sediment core was collected from Emerald Lake, Macquarie Island, using a gravity corer from a water depth of 1.5 m in March 2006 (Figure 2.4). The core was sub-sampled on-site at 0.5 cm intervals. Samples were stored at 4 °C until analysis.

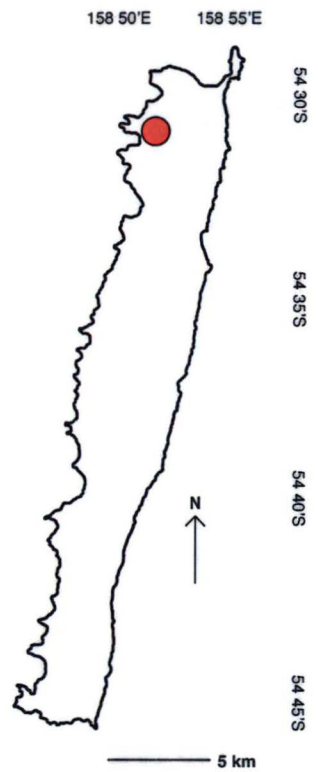


Figure 2.4: Location of Emerald Lake, sub-Antarctic Macquarie Island indicated by the red dot.

2.3 Preparation of diatom samples

Diatom samples from the reference sites and sediment cores were prepared using standard methods (based on Battarbee *et al.* 2001). A small amount of sediment from each sample was placed in a 100 mL conical flask and 40 mL of 10% hydrogen peroxide was added. Samples were loosely covered and left for 3 days to ensure all organic matter was digested. Aliquots were transferred to 10 mL test

tubes and centrifuged at 2000 rpm for 3 minutes. The supernatant was discarded and centrifugation repeated until all of the sample was transferred. Samples were then washed and centrifuged 3 times. Cleaned diatom residues were pipetted onto cover slips and completely dried on a hotplate at 50 °C. Coverslips were attached to glass slides with Norland optical adhesive 61 (refractive index 1.56) and placed under a UV lamp to cure.

At least 400 frustules were counted per sample, following methods of Battarbee (1986), using a Zeiss 20 light microscope and oil immersion at 1000x magnification. Diatoms were photographed using a Zeiss Axioscope microscope with an Axiocam digital camera and Axiovision software (Zeiss). The relative abundance of all species (including unidentified forms) were recorded as a percentage of the total number of frustules counted (Battarbee *et al.* 2001). Taxonomy was principally based on Australian taxonomic references (i.e. Hodgson *et al.* 1997, John 1983, Sonneman *et al.* 2000, Vyverman *et al.* 1995) and datasets (i.e. Hodgson *et al.* 1996, Saunders *et al.* 2007, Taffs 2005), and sub-Antarctic and Antarctic taxonomic references (i.e. Roberts & McMinn 1999, Van de Vijver *et al.* 2002a), with additional reference to European floras (e.g. Witkowski *et al.* 2000). Final species lists for each dataset were developed consisting of species occurring with ≥ 1% maximum relative abundance. This resulted in 155 species in the Victorian dataset, 130 species in the Tasmanian dataset, 195 species in the combined dataset and 129 species in the Macquarie Island dataset.

2.4 Analytical methods

To aid interpretation, the sediment cores were also analysed using the following measurements:

(i) The Lake King sediment core was analysed for chlorophyll *a* concentration and total organic matter at every interval, and particle size and total carbon, nitrogen and sulphur contents at 5 cm intervals.

(ii) The Emerald Lake sediment core was analysed for particle size and total carbon, nitrogen and sulphur contents at 2 cm intervals.

2.4.1 Chlorophyll a

Chlorophyll *a* was extracted from the sediment in 10 mL of methanol and measured at 440 nm on a Turner Designs 10AU Flurometer using the acidification method of Holm-Hansen *et al.* (1965). Chlorophyll *a* data were expressed relative to total organic matter content (TOM), which was determined by loss on ignition using the method of Dean (1974). Both of these analyses were undertaken at the University of Tasmania, Hobart.

2.4.2 Particle size

Particle size was measured at 5 cm intervals using a Malvern Mastersizer S Laser Particle Size Analyser at the Australian Nuclear Science and Technology Organisation (ANSTO), Sydney, following their in-house protocol. Approximately 0.5 g of wet sediment from each sample was dispersed in water and pumped through a measurement chamber in the laser particle analyser. The particle size distribution of solids with a diameter in the range 0.05 μm to 880 μm was determined.

2.4.3 Total sediment carbon, nitrogen and sulphur

Total sediment carbon, nitrogen and sulphur were measured using a LECO CNS 2000 analyser at ANSTO, following their in-house protocol. Samples were dried at 40 °C for 3 days. 2.0 g of sample were weighed into ceramic crucibles with 1.0 g of Com-Cat accelerator and samples were mixed. Samples were placed into the analyser and heated to 1400 °C to determine the percentage of total carbon, nitrogen and sulphur in the sediment.

2.4.4 Dating methods

Sediment chronologies for each sediment core were established using the lead-210 (^{210}Pb) dating technique (Goldberg 1963, Robbins 1978, Appleby & Oldfield 1992). Radiocarbon (^{14}C) dating (of bulk sediments) was also used to date the Emerald Lake sediment core.

(a) ^{210}Pb dating

^{210}Pb is the most commonly used dating tool for dating sediments up to 150 years old (Appleby 2001). It is a naturally occurring radioisotope and occurs as one of the radionuclides in the ^{238}U decay series (Appleby 2001, Figure 2.5).

^{210}Pb enters water bodies either via atmospheric deposition or erosion. It is deposited on the sediment surface and is in 'excess' of what is already *in situ* with ^{226}Ra. This decays and the concentration of initial ^{210}Pb activity in each sediment layer at the time of its deposition can be calculated. Based on the half-life of ^{210}Pb (i.e. 22.26 years) and sedimentation rate that is determined, the age of each layer of sediment can be estimated (Appleby 2001).

^{238}U (4.51×10^9 y)
↓
^{226}Ra (1602 y)
↓
^{222}Rn (3.82 d)
↓
^{210}Pb (22.26 y)
↓
^{210}Po (138.4 d)
↓
^{206}Pb

Figure 2.5: ^{238}U decay series and the principal radionuclides involved in the production of ^{210}Pb. Note: radioactive half-lives are in brackets, y = years, d = days.

Unsupported ^{210}Pb activities were measured in bulk sediment samples prepared by the author at the ANSTO Institute for Environmental Research following methods described by McMinn *et al.* (1997) and Harrison *et al.* (2003).

(i) Sample preparation for polonium analysis

Samples were oven-dried at 50 °C for 3 days and ground to pass through a 150 μm sieve. 10 dpm (disintegrations per minute) of ^{133}Ba and 10 dpm of ^{209}Po tracers

were added to approximately 5 g of each dry sample. 25 mL of concentrated HNO_3 was added and the samples evaporated to dryness on a hotplate at 90 °C. Once dry, samples were treated with 25 mL of 10 % H_2O_2. Once the reaction had ceased, 25 mL of concentrated HCl were added and the samples refluxed for 4-6 hours on a water bath.

Samples were then transferred to centrifuge tubes with 6 M HCl and centrifuged at 4600 rpm for 3 minutes. The supernatant was transferred to a separating funnel. The solid residue was washed several times with each resultant supernatant being combined and the sediment residue discarded. Excess iron in the 6M HCl supernatant was removed by extraction using diethyl ether and samples dried on a hotplate at 90 °C.

Once dry, samples were dissolved in 50 mL 0.1 M HCl. Thirty mL of reagent water was added, followed by 100 µL 1.0 M citric acid to complex trace iron and chromium. Ten mg of bismuth holdback carrier was added to inhibit auto-deposition of radioactive Bi^{3+} in the samples.

The pH of the samples was adjusted to 1.5 with concentrated ammonium hydroxide solution. The samples were heated to 90 °C and 1 g of hydroxylammonium chloride was added along with a silver disc. The solutions were mixed continuously for 15-20 minutes before being placed on a hotplate (60 °C) for a further 6 hours. The discs were moved periodically to ensure air bubbles did not form, as this would limit the surface area for ^{209}Po to auto-deposit. A watch glass was placed on top of the beakers to ensure that the solution did not evaporate, as this would change the pH of the solutions. Once auto-deposition was completed the silver discs were removed, washed with reagent water, rinsed with 95 % ethanol and air dried before using alpha-spectrometry to determine ^{209}Po recovery and total ^{210}Pb activity (via ^{210}Po activity) in the samples.

(ii) Sample preparation for radium analysis

All remaining solutions from the sample preparation for ^{209}Po analysis were diluted to 800 mL. While on a magnetic stirrer, 20 mL of concentrated sulphuric acid and 100 mL of 20 % sodium sulphate were added to each sample. Ten mL of 10 mg mL^{-1} Pb^{2+} carrier in 0.1 M HNO_3 were added to form a fine lead sulphate

precipitate that co-precipitates ^{226}Ra and ^{133}Ba. The solutions were left to settle overnight. The supernatant was removed by water pump suction and the lead-radium-barium sulphate co-precipitate was transferred to centrifuge tubes with 50 % ethanol and centrifuged at 4600 rpm for 3 minutes. The supernatant was discarded. This was repeated until all of the co-precipitate had been transferred to the centrifuge tubes.

The co-precipitate was dissolved in 5 mL of 0.2 M Na_5DTPA (DTPA = diethylene triamine pentacetic acid) and 5 mL of Na_2SO_4. One drop of thymol blue was added and the pH adjusted to > 9. Samples were then treated in an ultrasonic bath for half an hour to dissolve all of the precipitate. Two drops of methyl red indicator were added and the samples passed through 0.45 μm filters into vials to remove any solid matter. Simultaneously, 2 mL of 1:1 acetic acid and water and colloidal barium sulphate ($BaSO_4$) seeding solution were added to the filtered samples. The samples were left in cold water for 30 minutes before proceeding.

The samples were filtered through smooth-surfaced Millipore 'VV' membrane filters in a lock-seal Gelman filter apparatus set. The vials and filter funnels were rinsed with 50% ethanol to ensure the maximum amount of ^{226}Ra and ^{133}Ba co-precipitate was collected. The filter papers were air dried, then analysed. ^{133}Ba activity, used to infer chemical yield, was determined by gamma spectrometry on a low background HPGe gamma detector. ^{226}Ra activity was determined by alpha spectrometry after ^{133}Ba chemical yield correction.

(iii) Modelling ^{210}Pb

The unsupported ^{210}Pb activities were modelled using the Constant Initial Concentration (CIC, Robbins 1978) and the Constant Rate of Supply (CRS, Appleby & Oldfield 1978) ^{210}Pb dating models. The CIC model assumes that the supply of ^{210}Pb to the system varies directly in proportion to the sedimentation rate, implying the sediment profile exhibits an exponential decrease in unsupported ^{210}Pb (Gelen *et al.* 2003, Appleby 2001). This model assumes the majority of ^{210}Pb enters the system via river and catchment inputs rather than by atmospheric deposition, which is characteristic of sites with large catchments and river inputs (Appleby & Oldfield 1992). The CRS model assumes the rate of

supply of atmospheric ^{210}Pb is constant. Therefore, in any sediment interval, the concentration of unsupported ^{210}Pb is inversely proportional to the sedimentation rate (Appleby and Oldfield 1978). The most appropriate ^{210}Pb dating model for each site was selected by considering the basic assumptions of both models in light of catchment and water body size and the most likely unsupported ^{210}Pb pathway. For these reasons the CIC model was selected for age and mass accumulation rate calculations for both sediment cores.

(b) ^{14}C dating

^{14}C dating is the most widely used dating tool for sediments aged c. 300 to c. 40,000 years old (Björck & Wohlfarth 2001). ^{14}C dating was used to determine the age of the Emerald Lake core as it extended beyond the age range for ^{210}Pb. Bulk sediments (as no macrofossils were present) were sent to the Rafter Radiocarbon Laboratory, New Zealand for analysis using Accelerator Mass Spectrometry. Dates were calibrated based on the Southern Hemisphere Atmospheric correction (McCormac *et al.* 2004). As the lake water was not derived from the sea, no reservoir correction was necessary.

2.5 Development of transfer functions

2.5.1 Diatom-environment relationships

Each dataset underwent the same statistical procedures to determine the independent, statistically significant, environmental variables controlling diatom species abundance and occurrence at each location. Each environmental variable was checked for skewness and log(x+1) transformed where necessary (i.e. log(x+1) transformation was used if it resulted in more normally distributed data). Principal Components Analysis (PCA) was performed on the environmental data to determine major gradients. Centering and standardisation were used as environmental variables had different scales (Bennion & Smith 2000). Scaling was focused on inter-species distances and species scores were divided by the standard deviation.

Detrended Correspondence Analysis (DCA) with detrending by segments and downweighting of rare species was performed on the species data to establish whether species distribution was unimodal or linear. All species data were log(x+1) transformed for the subsequent statistical analyses and development of the transfer functions. As the gradient lengths of the DCAs were > 2 standard deviation units, unimodal ordination techniques were used to explore the species-environment relationships.

An initial Canonical Correspondence Analyses (CCA) was performed with scaling focussed on inter-species distances, biplot scaling and downweighting of rare species to determine the percentage of species variance explained by the environmental variables. This was determined by dividing the sum of all canonical eigenvalues by the sum of the total inertia.

Variance Inflation Factors (VIFs) were identified and any environmental variables with VIFs > 20 were removed. Any variables with site-environment influences > 8 times were also removed (as a VIF > 20 for an environmental variable indicates that it is almost perfectly correlated with another, while a site-environment influence > 8 indicates the environmental variable has a limited independent explanatory contribution in the data set; Werner & Smol 2005). A series of CCAs with Monte Carlo permutation tests were performed to determine which environmental variables accounted for statistically significant variations in the diatom data for each dataset. CCAs with each environmental variable as the sole environmental variable were performed, followed by separate CCAs of each environmental variable with the remainder as covariables. Based on the p value of each environmental variable (i.e. $p < 0.05$ indicates the relationship is significant), one environmental variable at a time was removed (i.e. the environmental variable with the highest p value) and a series of CCAs performed again with each remaining environmental variable and the rest as covariables. This was continued until only the significant environmental variables remained. Variance partitioning was then used to determine the amount of variation explained by each variable and the interaction between them. All ordinations were performed using the software program R (R Development Core Team 2006).

2.5.2 Diatom-based transfer functions

Transfer functions were developed using simple weighted averaging (WA) with inverse and classical deshrinking, and with/without tolerance downweighting. Weighted averaging partial least squares (WAPLS) was also used to determine which model led to the best performing transfer functions for each environmental variable in each dataset. Performance was assessed using cross validation (i.e. jackknifing and bootstrapping). The transfer functions with the best correlations (r^2), best predicted correlations (r^2p), lowest root mean squared errors (RMSE) and lowest root mean squared errors of prediction (RMSEp) were identified and used. Simple WA was also used to determine species optima and tolerances in each dataset to investigate diatom ecological preferences in each region. All transfer functions were developed using the software program C2 version 1.4 (Juggins 2003).

2.5.3 Species richness

Species richness in the Emerald Lake sediment core was calculated using the Simpsons Index of Diversity (Simpson 1949):

$$\text{Simpons Index of Diversity} = 1 - (\sum n[n-1])/(N[N-1])$$

where n = total number of individuals of a species and N = total number of individuals of all species.

Diatom-environment relationships in southeast Australian coastal water bodies: development of transfer functions and evaluation of applications in future management

3.1 Introduction

Declining water quality in coastal areas is a well documented problem in many parts of the world (Nixon 1995, de Jonge *et al.* 2002). The coastal zone is under increasing pressure from human activities largely stemming from population growth and exploitation of coastal resources (Roy *et al.* 2001, Harvey & Caton 2003). Approximately 70% of the world's population and 85% of the Australian population is concentrated in settlements within 50 km of the coast (Zann 1995, Paerl *et al.* 2003). Worldwide, the conservation and management of coastal environments has lagged behind terrestrial environments. The effects of poor water quality in freshwater systems have been well studied and understood since the mid 20th century. In contrast, an awareness of water quality issues in coastal environments has only developed in the last 20-30 years (Elliot & de Jonge 2002).

Most coastal catchment areas in eastern and southern Australia have been extensively cleared, primarily for agricultural purposes, which has resulted in increased land erosion, sedimentation rates and nutrient loads to coastal water bodies. In turn, this has led to a loss of biodiversity, deterioration in water quality, eutrophication and increased frequency of harmful algal blooms, decline and degradation of important habitats such as seagrasses, mangroves and saltmarshes, disruption to migratory bird populations and declining fish populations (Zann 1995, Paerl *et al.* 2003). However, the development and assessment of appropriate conservation, management and restoration strategies is hampered by a lack of baseline data and information on the rates of natural and human-induced change and recovery (Vaalgamaa & Korhola 2004). Few Australian coastal ecosystems have been monitored for more than a decade and little information is available prior to the 1960s (Tibby 2004). Monitoring programmes are often sporadic, based on a series of spot measurements, established with a specific focus, usually started after environmental problems have been identified and constrained by the resources available to the organisation undertaking the monitoring. Despite these limitations, many national and international initiatives have been implemented on

a variety of spatial scales to address poor water quality in coastal waters (Andersen *et al.* 2004). As a result, management strategies often lack the long term perspective needed to understand and address water quality issues (Swetnam *et al.* 1999).

Successful management requires identifying realistic and appropriate 'baselines'. This involves knowledge and understanding of the original or 'pre-impact' condition of the environment, the extent and direction of change, current conditions and natural variability (Weckström *et al.* 2004). Differentiating between natural and human-induced change is also essential, particularly when assessing likely responses to climate change and remediation options. Little is known about 'baseline' conditions in Australian coastal environments as historical documentation is virtually absent prior to European settlement and is sparse during the early settlement period (Reid & Ogden 2006).

In the absence of long term water quality monitoring, palaeolimnological techniques provide a method for determining baseline conditions, rates and direction of change and natural variability. This is particularly important at sites of high conservation status as their condition at the time of listing is not usually known, but management aims are generally focused on maintaining or achieving 'good ecological status' (e.g. listing of sites under the Ramsar agreement, which require signatory nations to protect wetlands of international importance and maintain the ecological character of listed sites, Environment Australia 2005).

Consequently, palaeolimnological studies have a key role to play in coastal management. They have the potential to provide a continuous record of change over a time frame useful for addressing management questions. Accurate quantification and interpretation of past changes are essential to allow the development of more effective management strategies. Previous palaeolimnological studies have demonstrated that many problems caused by anthropogenic activities in and around aquatic systems are reversible and that once an impact has been reduced or removed, the ecosystem starts to recover (e.g. Hodgson *et al.* 2000, McMinn *et al.* 2003, Tikkanen *et al.* 1997), even if it is not reflected in the water chemistry (e.g. Kwandrans *et al.* 1998). This is important for being able to evaluate the capacity of coastal ecosystems to adapt and respond to future changes, particularly predicted climate change and further pressure from human activities (Duke *et al.* 2003, Davis & Kloop 2006).

As outlined in Chapter 1, diatoms are one of the most widely used biological indicators in palaeolimnological studies, particularly for water quality assessments (Dixit *et al.* 1992). At present, little is known about the diatom species composition of southeast Australian coastal habitats, the main environmental gradients influencing them, their potential for use in the development of diatom-based inference models (i.e. transfer functions) and how they can contribute to water quality assessments.

The development of diatom-based transfer functions and application of a palaeolimnological approach are a potentially valuable set of management tools. So far in Australian coastal management, this approach has not been utilised.

3.2 Aims

The Aims of this Chapter are to:

1. Determine the differences and similarities in major environmental gradients occurring in Tasmanian and Victorian coastal water bodies;
2. Provide baseline, species-level data on the composition and distribution of surface sediment diatom communities of coastal water bodies in Tasmania and Victoria;
3. Investigate and identify the environmental gradients influencing diatom distribution in Tasmanian and Victorian coastal water bodies; and
4. Develop transfer functions based on these environmental variables.

3.3 Results

Water and surface sediment samples were collected from 36 sites in Tasmania and 45 sites in Victoria. The sites ranged from 37.50°S - 42.92°S and 144.4°E - 149.7°E (Figure 3.1). The water and surface sediment samples were used to develop Tasmanian and Victorian diatom-based reference datasets to investigate diatom-environment relationships in the two regions and determine which environmental variables could potentially be used to develop transfer functions. The datasets were also combined to explore overall environmental influences.

3.3.1 Limnology

Sites were sampled twice during the period of data collection (August-September 2004 and February-March 2005) and an average of the two water quality measurements for each site was used in the statistical analyses.

The water quality characteristics of the sites varied widely from oligotrophic to eutrophic; fresh to hypersaline; acidic to alkaline; and low to high turbidity and dissolved oxygen. A summary of the water quality data is outlined in Table 3.1. The location (including site code) and water quality data for each site are presented in Appendix 1.

Mean and maximum nitrate/nitrite and phosphate concentrations were higher in Victorian sites, but temperature and turbidity means and ranges were similar. The ranges of dissolved oxygen and salinity were greater at Victorian sites compared to Tasmanian sites, while the pH range at Tasmanian sites was greater than at Victorian sites (Table 3.1).

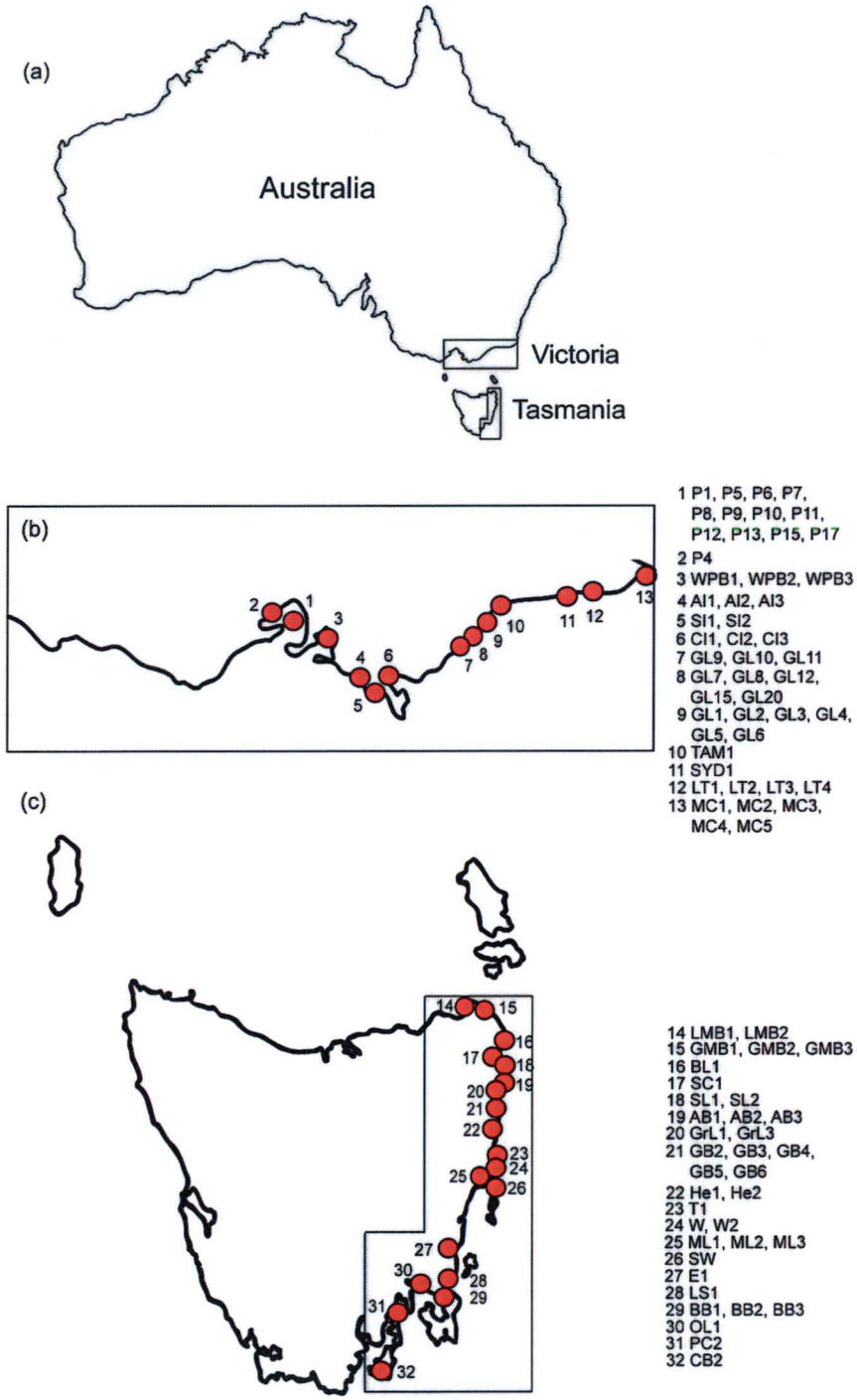


Figure 3.1: (a) Location of study area in the Tasmanian and Victorian datasets; (b) location of sampling sites in Victoria and (c) Tasmania with specific sites numbered. See Appendix 1 for specific location and full names of sampling sites.

Table 3.1: Summary of water quality data for the Tasmanian and Victorian datasets separately and combined. Note: N = nitrate/nitrite, P = phosphate, Si = silicate.

	Mean	Median	Min	Max	Mean	Median	Min	Max
	Latitude (°S)				**Longitude** (°E)			
Tasmania	41.50	41.31	37.85	42.96	148.1	148.3	147.5	148.3
Victoria	38.06	37.91	37.50	38.84	146.7	146.3	144.4	149.7
Combined	39.63	38.67	37.50	42.96	147.4	148.0	144.4	149.7
	Dissolved oxygen (mg L^{-1})				**Nitrate/nitrite** (μg N L^{-1})			
Tasmania	9.28	9.58	4.06	13.0	8.00	7.17	3.02	52.5
Victoria	4.99	4.50	0.61	18.9	63.4	2.04	0.00	696
Combined	6.89	6.71	0.61	18.9	38.4	2.43	0.00	696
	pH				**Phosphate** (μg P L^{-1})			
Tasmania	7.90	7.79	7.10	8.87	8.24	4.76	1.13	67.5
Victoria	7.94	7.96	7.46	8.46	47.7	13.5	0.00	348
Combined	7.92	7.94	7.10	8.87	30.2	6.27	0.00	348
	Salinity (ppt)				**Silicate** (μg Si L^{-1})			
Tasmania	25.0	29.1	1.75	35.3	345	280	46.0	1132
Victoria	27.7	31.1	0.75	40.0	410	305	55.3	1291
Combined	26.5	29.6	0.75	40.0	380	290	46.0	1291
	Temperature (°C)				**Turbidity** (NTU)			
Tasmania	15.1	15.3	10.4	18.7	18.8	6.5	0.0	151
Victoria	16.2	16.4	9.6	19.2	17.1	6.0	0.0	140
Combined	15.7	15.9	9.6	19.2	17.8	6.0	0.0	151

3.3.2 Diatoms

In total, 399 diatom species were identified: 247 in Tasmania and 342 in Victoria. Of these, 56 species occurred in Tasmanian sites only, while 157 species occurred only in Victorian sites.

A list of species including occurrence and distribution is outlined in Appendix 2. Images of the taxa are illustrated in Appendix 3. Of the species identified in the Tasmanian and Victorian datasets, only those species occurring with a maximum relative abundance of ≥ 1% were included in the statistical

analyses (i.e. 130 taxa and 155 taxa respectively). These taxa represent 95.2-100% (mean 98.2%) and 94.6-100% (mean 98.4%) respectively of the total diatom count remaining for each site.

The number of taxa per sample in the Tasmanian dataset ranged from 15-60 (mean 43 taxa). Eleven taxa were widespread and occurred in ≥ 30 sites and 35 taxa were abundant in particular samples, occurring with ≥ 10% maximum relative abundance (Table 3.2). Of these, eight were both widespread and dominant: *Catenula adherens*, *Cocconeis placentula*, *Cocconeis scutellum*, *Navicula salinarum* var. *salinarum*, *Opephora pacifica*, *Opephora guenter grassi*, *Planothidium delicatulum* and *Planothidium hauckianium*.

The number of taxa per sample in the Victorian dataset ranged from 29 to 84 (mean 57 taxa). Twenty-one taxa were widespread and occurred in ≥ 30 sites and 22 taxa were abundant in particular samples, occurring with ≥ 10% relative abundance at least once in the dataset (Table 3.3). Of these, 10 taxa were both widespread and dominant: *Achnanthes fogeddii*, *Catenula adherens*, *Cocconeis scutellum var.* 1, *Navicula perminuta*, *Navicula recens*, *Nitzschia* cf. *valdestriata*, *Opephora pacifica*, *Opephora guenter grassii* and *Planothidium delicatulum*.

Table 3.2: Most widespread (i.e. occurring in ≥ 30 sites) and abundant (i.e. occurring with ≥ 10 % relative abundance in ≥ 1 sample) diatom taxa in the Tasmanian dataset. Note: n = number of sites taxon occurs in, Max = maximum relative abundance (%), Mean = mean relative abundance in the dataset (%), $Mean_{adj}$ = mean relative abundance of taxon, excluding 0 values (%), Median = median relative abundance in the dataset (%), Med_{adj} = median relative abundance of taxon, excluding 0 values (%), Occ = occurrence, W = widespread, D = dominant, W/D = widespread and dominant.

Name	code	n	Max	Mean	$Mean_{adj}$	Med_{adj}	Occ
Achnanthes brevipes var. *angustata*	EPI1a	29	17.12	1.51	2.19	0.73	D
Achnanthes brevipes var. *intermedia*	EPI1	3	10.87	0.28	3.88	0.51	D
Actinocyclus sp. 1	CEN7	1	18.85	0.45	18.85	18.85	D
Actinocyclus subtilis	CEN10	9	40.33	1.09	5.07	0.47	D
Amphora sp. 3	AMPcof2	23	10.87	1.15	2.10	1.49	D
Amphora acutuscula	AMPcof	33	7.97	1.84	2.34	1.74	W
Catenula adherens	AMP1	36	39.53	4.93	5.76	3.49	W/D
Cocconeis peltoides	ACH3	27	13.90	1.93	3.00	1.73	D
Cocconeis peltoides var. 1	DIP7	20	28.22	2.60	5.46	1.96	D
Cocconeis placentula	COCpla	36	51.00	6.19	7 22	5.01	W/D
Cocconeis placentula var. *euglypta*	COCplae	12	26.55	0.96	3.35	1.11	D
Cocconeis scutellum	COCscu	34	30.47	2.93	3.52	1.21	W/D
Cyclotella choctawhatceeana	CYCstr2	29	29.01	2.07	2.99	0.93	D
Diatomella cf. *balfouriana*	UNK37b	7	51.38	2.17	13.05	4.73	D
Diploneis cf. *domblitlensis* var. 1	FAL10	3	10.96	0 31	4.41	1.50	D
Fragilaria ellipta agg	CEN5	8	11.5	0.51	2.66	0.87	D
Frustulia rhomboides var. *saxonica*	UNK206	3	16.32	0.44	6.16	1.84	D
Grammatophora oceanica	GRAmar	19	41.87	1.92	4.24	0 76	D
Mastogloia pusilla	MAS2a	10	24.87	0 91	3.81	0.93	D
Melosira lineata var. *juergensis*	UNK43	9	44.37	1.22	5.70	0.25	D
Navicula perminuta	NAVper	34	14 29	1.83	2.26	1.27	D
Navicula recens	NAV1	30	5.75	1.34	1.88	0.75	W
Navicula salinarum var. *salinarum*	NAV3	30	11.47	1.90	2.57	1.52	W/D
Nitzschia cf. *valdestriata*	NITval	25	14.85	1.20	1.86	0.75	D
Opephora guenter grassu	OPEgue	33	15.33	3.39	4.18	2.88	W/D
Opephora pacifica	OPEbur	38	64.22	5.96	6.76	3.48	W/D
Planothidium delicatulum	PLAdel	37	28.75	2.91	3.31	1.88	W/D
Planothidium hauckianium agg.	PLAhau	34	25.69	3.67	4.54	2.59	W/D
Rhopalodia acuminata	RHA3	25	34.15	1.48	2.39	0.86	D
Trachyspenia australis var. *australis*	VIK8a	4	12.20	0.40	4.24	2.13	D
Unknown sp. 1	NAV32a	1	10.05	0.24	10.05	10.05	D

Table 3.3: Most widespread (i.e. occurring in ≥ 30 sites) and abundant (i.e. occurring with ≥ 10 % relative abundance) diatom taxa in the Victorian dataset. Note: n = number of sites taxon occurs in, Max = maximum relative abundance (%), Mean = mean relative abundance in the dataset (%), $Mean_{adj}$ = mean relative abundance of taxon, excluding 0 values (%), Median = median relative abundance in the dataset (%), Med_{adj} = median relative abundance of taxon, excluding 0 values (%), Occ = occurrence, W = widespread, D = dominant, W/D = widespread and dominant.

Name	code	n	Max	Mean	$Mean_{adj}$	Med_{adj}	Occ
Achnanthes brevipes var, *angustata*	EPI1a	34	5.91	1.77	2.45	1.75	W
Amphora sp. 1	AMP3	10	15.21	0.76	3.41	0.97	D
Amphora sp. 2	AMP14a	31	4.13	0.80	1.25	0.99	W
Amphora acutiuscula	AMPcof	34	5.70	0.85	1.25	0.75	W
Amphora cf. *strigosa*	AMP9	31	6.05	0.99	1.58	0.91	W
Bacillaria paxillifer	NITscal	31	5.16	0.81	1.30	0.67	W
Biremis lucens	UNK7	30	9.90	1.19	2.05	0.97	W
Catenula adherens	AMP1	43	39.47	6 77	7.82	4.99	W/D
Cocconeis sp. 1	UNK107	14	16.5	1.02	3.28	1.57	D
Cocconeis scutellum	COCscu	34	5.50	1.31	1.84	1.25	W
Cocconeis scutellum var. 1	COCdis	32	56.22	3.58	6.57	1.45	W/D
Coscinodiscus centralis	CEN1	29	54.25	2.81	5.61	3.03	D
Cyclotella striata	CYCstr	19	12.80	0.95	2.25	0.48	D
Fallacia pseudony	FAL5	32	3.45	0.70	1.06	0.72	W
Fragilaria ellipta agg.	CEN5	27	14.46	1.29	2.15	1.25	D
Grammatophora macilenta	GRAmac	3	16 75	0.38	5.75	0.25	D
Grammatophora oceanica	GRAmar	27	13.85	1.28	2.13	1.80	D
Melosira nummuloides	MEL1	11	16.46	0.61	2.51	1.04	D
Navicula sp. 1	UNK30	35	8.10	1.43	2.01	1.10	W
Navicula cf. *lusoria*	ACH14	13	21.16	1.19	4.13	2.15	D
Navicula perminuta	NAVper	34	12.21	1.74	2.59	1.46	W/D
Navicula recens	NAV1	30	14.07	1.27	2.30	1.25	W/D
Nitzschia valdestriata	NITval	39	10.84	1.67	2.15	0.87	W/D
Opephora guenter grassi	OPEgue	35	27.65	3.77	5.48	3.10	W/D
Opephora pacifica	OPEbur	40	42.47	3.99	6.73	3.13	W/D
Paralia sp. 1	PARsul	16	12.00	0.79	2.24	0.74	D
Planothidium delicatulum agg	PLAdel	37	13.05	2.43	3.22	1.80	W/D
Planothidium hauckianium agg.	PLAhau	41	55.30	7.53	9.38	4.40	W/D
Pleurosigma cf. *salinarum*	GYRbal	24	12.56	0.89	1.67	1.37	D

3.3.3 Multivariate analyses

Multivariate analyses were used to determine major environmental gradients in the datasets and identify potential environmental variables for developing transfer functions. The Tasmanian and Victorian datasets were initially analysed separately, before being combined to investigate overall trends.

(a) Environmental data

Principal Components Analyses (PCA) was used to determine major environmental gradients in the Tasmanian and Victorian datasets. PCA was also used on the combined dataset with and without latitude and longitude to investigate the potential influence of location.

(i) Tasmanian environmental data

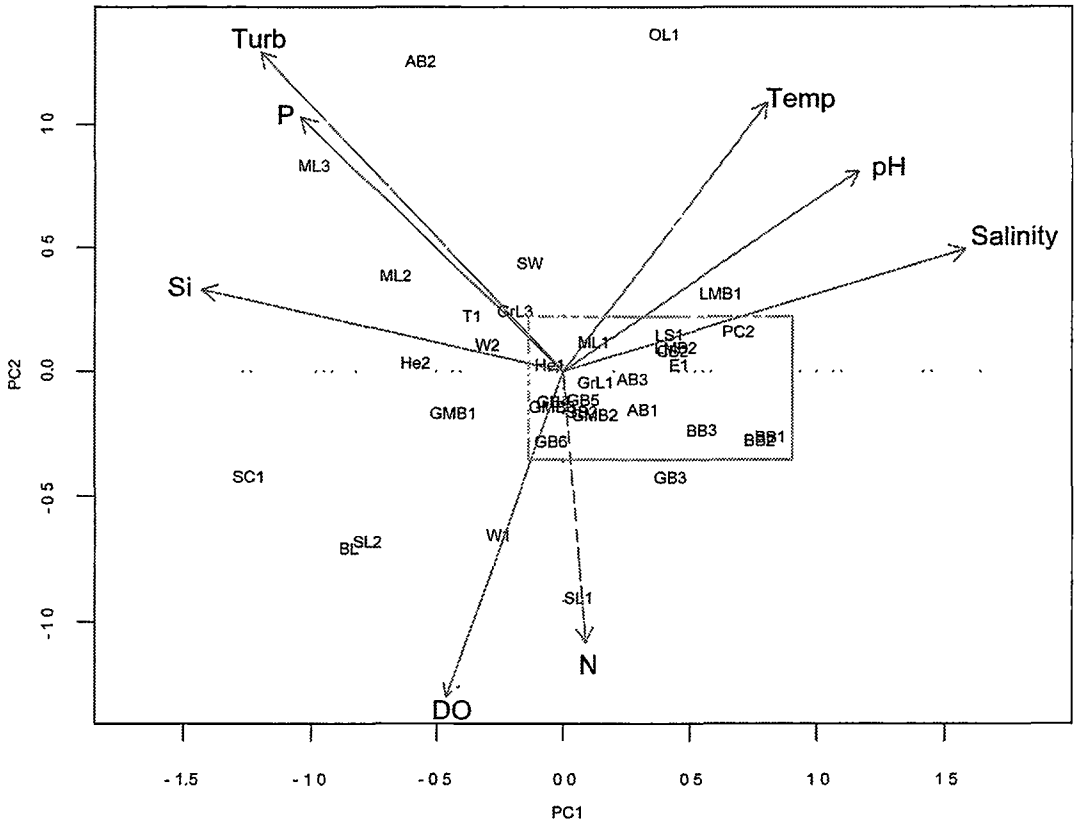
PCA of the Tasmanian environmental data showed that the first two axes explained 42.0% of the variation in the environmental data (Table 3.4). Silicate and salinity were closely correlated to axis 1, while nitrate/nitrite and to a lesser extent dissolved oxygen were closest to axis 2. Phosphate and turbidity were correlated to both axes, as were pH and temperature (Figure 3.2).

(ii) Victorian environmental data

PCA of the Victorian environmental data showed that the first two axes explained 40.9% of the variation in the environmental data (Table 3.4). Nitrate/nitrite was closest to axis 1, while pH was closest to axis 2. Turbidity was correlated to nitrate/nitrite, as were phosphate and silicate, which were correlated to both axes. Salinity, dissolved oxygen and temperature were also correlated to both axes and fell perpendicular to the nutrient gradients (except salinity, which was negatively correlated to silicate, Figure 3.3).

Table 3.4: Principal Components Analyses of the Tasmanian and Victorian datasets.

Axes variance	1	2	3	4	Total
Tasmanian dataset					
Eigenvalues	2.468	1.735	1.478	0.968	1.000
Cumulative % variance of environmental data	24.7	42.0	56.8	66.5	
Victorian dataset					
Eigenvalues	2.277	1.816	1.528	0.854	1.000
Cumulative % variance of environmental data	22.8	40.9	56.2	64.7	



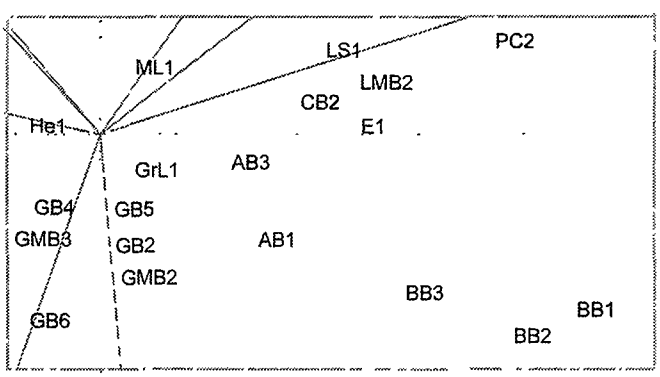


Figure 3.2: Principal Components Analysis of the environmental data in the Tasmanian dataset. Boxed region in the upper panel expanded below. Note: DO = dissolved oxygen, N = nitrate/nitrite, P = phosphate, Si = silicate, Temp = temperature, Turb = turbidity. See Appendix 1 for site names.

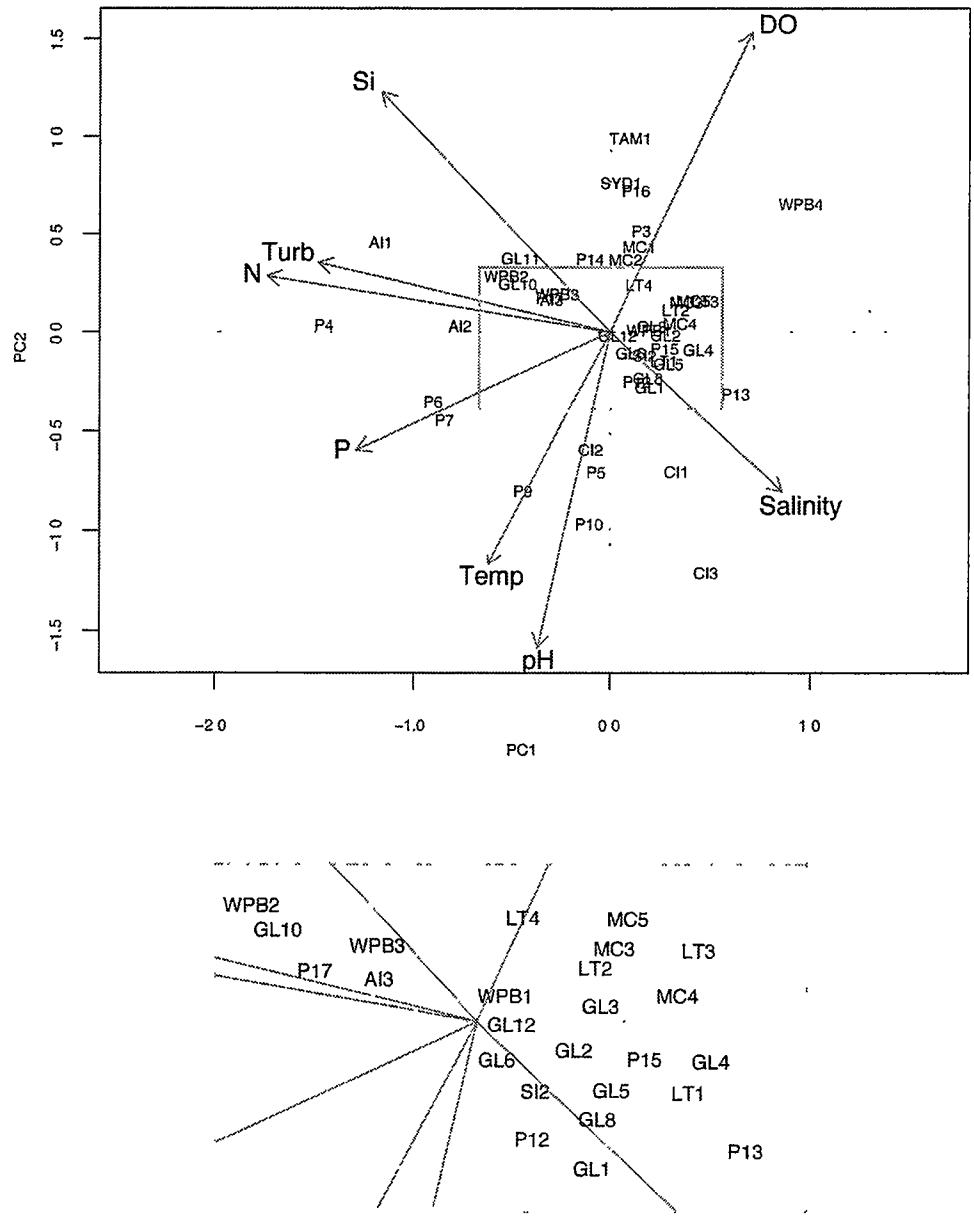


Figure 3.3: Principal Components Analysis of the environmental data in the Victorian dataset. Boxed region in the upper panel expanded below. Note: DO = dissolved oxygen, N = nitrate/nitrite, P = phosphate, Si = silicate, Temp = temperature, Turb = turbidity. See Appendix 1 for site names.

(iii) Combined Tasmanian and Victorian environmental data

In order to investigate the potential for combining the Tasmanian and Victorian datasets, the two were combined and the influence of geographical variables (i.e. latitude and longitude) determined. PCA of the combined dataset, including latitude and longitude, indicated that the first two axes explained nearly 50.0% of the variation in the environmental data (Table 3.5). Latitude was closely correlated to axis 1, as were longitude, phosphate and dissolved oxygen. Silicate and salinity were correlated to axis 2. Turbidity, nitrate/nitrite, pH and temperature were correlated to axes 1 and 2 (Figure 3.4).

To investigate overall water quality trends, PCA on the combined dataset without latitude and longitude was performed. This showed that the first two axes explained 41.7% of the variation in the environmental data (Table 3.5). Nitrate/nitrite was closely correlated to axis 1, pH was closely correlated to axis 2, while the remaining variables were correlated to both axes (Figure 3.5).

Table 3.5: Principal Components Analyses of the combined Tasmanian and Victorian dataset with and without longitude and latitude.

Axes variance	1	2	3	4	Total
Latitude and longitude included					
Eigenvalues	2.881	2.077	1.417	1.029	1.000
Cumulative % variance of environmental data	28.8	49.6	63.8	74.0	
Latitude and longitude excluded					
Eigenvalues	2.140	2.025	1.184	0.748	1.000
Cumulative % variance of environmental data	21.4	41.7	53.5	61.0	

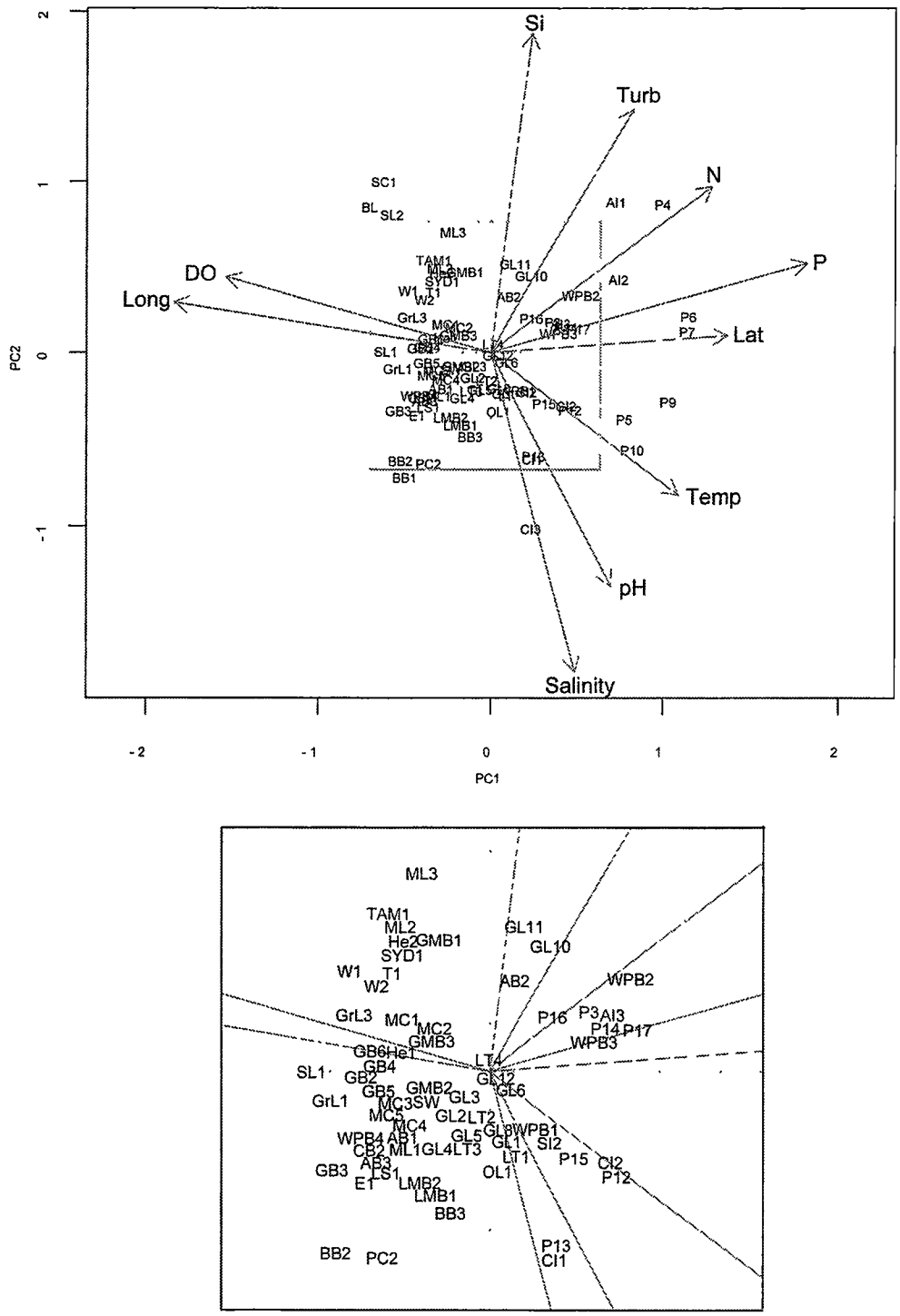


Figure 3.4: Principal Components Analysis of the environmental data in the Tasmanian and Victorian datasets including latitude and longitude. Boxed region in the upper panel expanded below. Note: DO = dissolved oxygen, Lat = latitude, Long = longitude, N = nitrate/nitrite, P = phosphate, Si = silicate, Temp = temperature, Turb = turbidity. See Appendix 1 for site names.

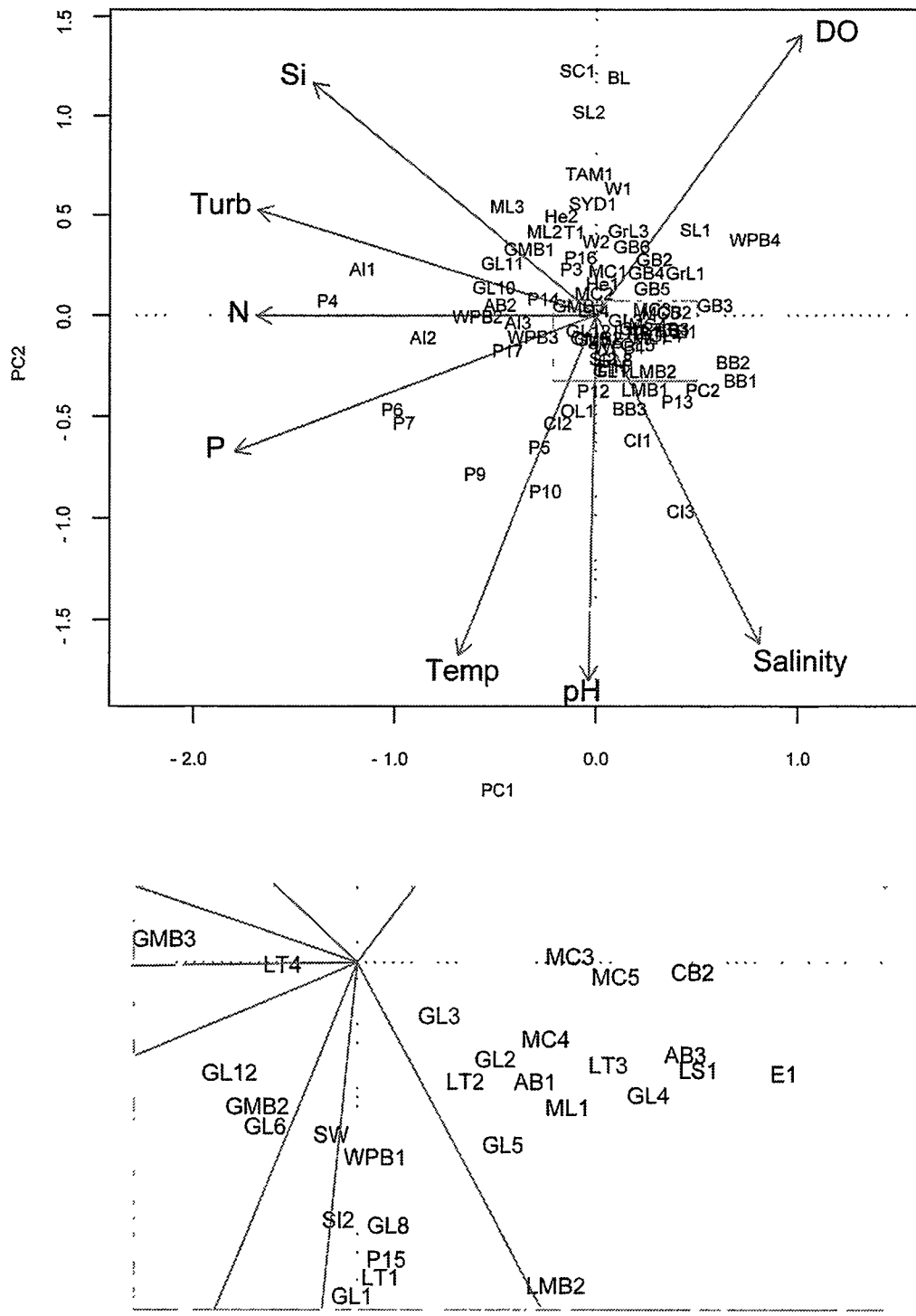


Figure 3.5: Principal Components Analysis of the environmental data in the Tasmanian and Victorian datasets without latitude and longitude. Boxed region in the upper panel expanded below. Note: DO = dissolved oxygen, N = nitrate/nitrite, P = phosphate, Si = silicate, Temp = temperature, Turb = turbidity. See Appendix 1 for site names.

(b) Diatom-environment relationships

Canonical Correspondence Analysis (CCA) and variance partitioning were used to determine major environmental gradients influencing diatom species distribution in the Tasmanian and Victorian datasets. CCA and variance partitioning were also used on the combined dataset with and without the influence of latitude and longitude to determine the potential influence of location and the possibility of combining the two datasets.

(i) Tasmanian dataset

CCA of the Tasmanian data indicated that the environmental variables explained 28.9% of the variation in the diatom data (Table 3.6). Nitrate/nitrite was strongly correlated to axis 2, while the remaining environmental variables were correlated to axes 1 and 2 (Figures 3.6-3.7).

Phosphate, salinity and temperature explained independent portions of the variance in the diatom data (as determined by forward selection) and CCA of these indicated they explained 13.6% of the variation in the diatom data (Figures 3.8-3.9, Table 3.6).

Table 3.6: Canonical Correspondence Analysis results of the Tasmanian dataset with all environmental variables and forward selected variables (i.e. phosphate, salinity and temperature).

Axis	1	2	3	4
All variables				
Eigenvalues	0.173	0.107	0.098	0.096
Sum of canonical eigenvalues	0.711			
Sum of all eigenvalues	2.457			
Forward selected variables only				
Eigenvalues	0.144	0.095	0.094	
Sum of canonical eigenvalues	0.333			
Sum of all eigenvalues	2.457			

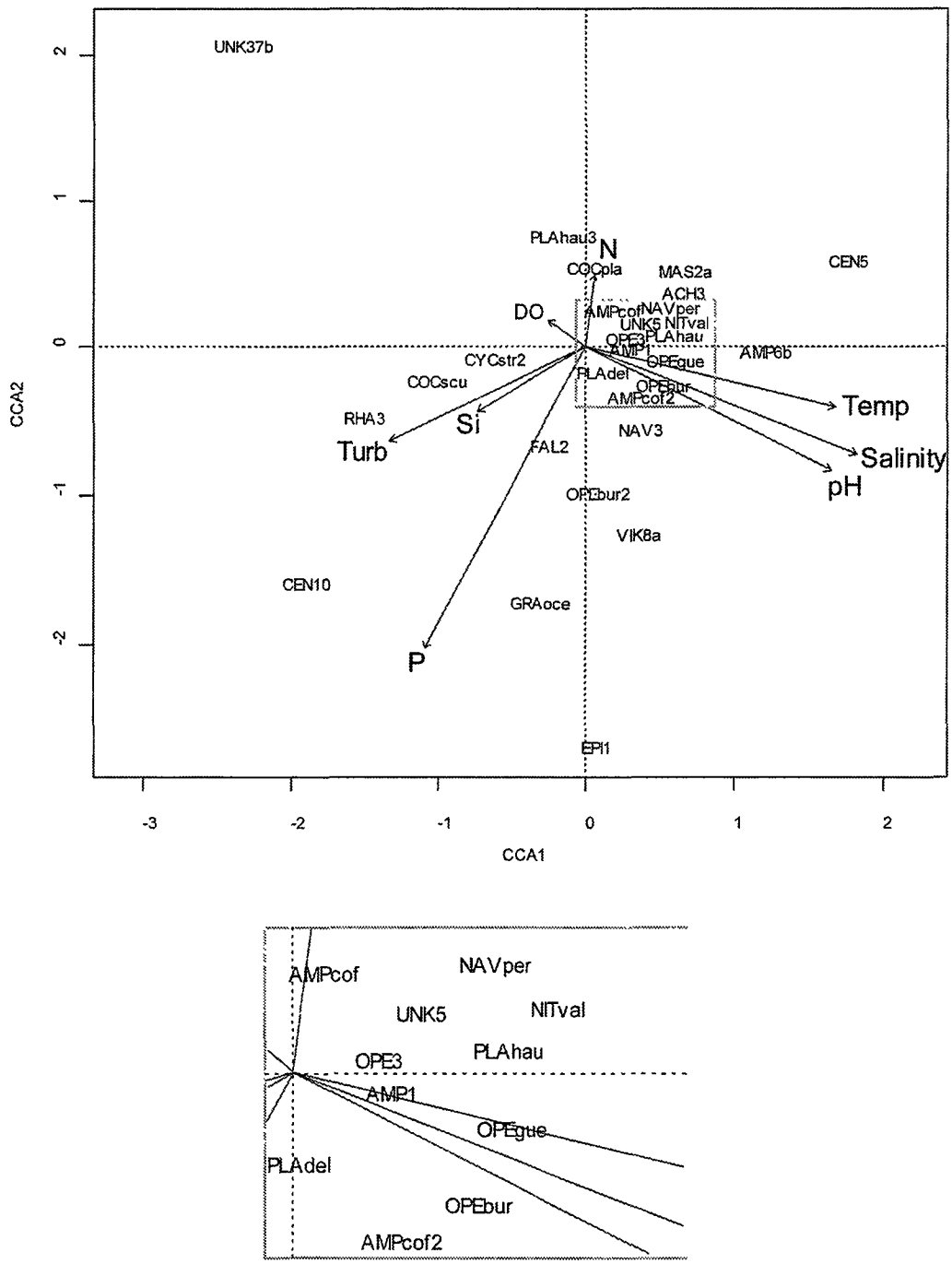


Figure 3.6: Canonical Correspondence Analysis of the Tasmanian dataset with all environmental variables. Dominant species (i.e. species occurring with a maximum relative abundance ≥ 10% and occurring in ≥ 10 samples) displayed. Boxed region in the upper panel expanded below. Note: DO = dissolved oxygen, N = nitrate/nitrite, P = phosphate, Si = silicate, Temp = temperature, Turb = turbidity. See Appendix 2 for species names.

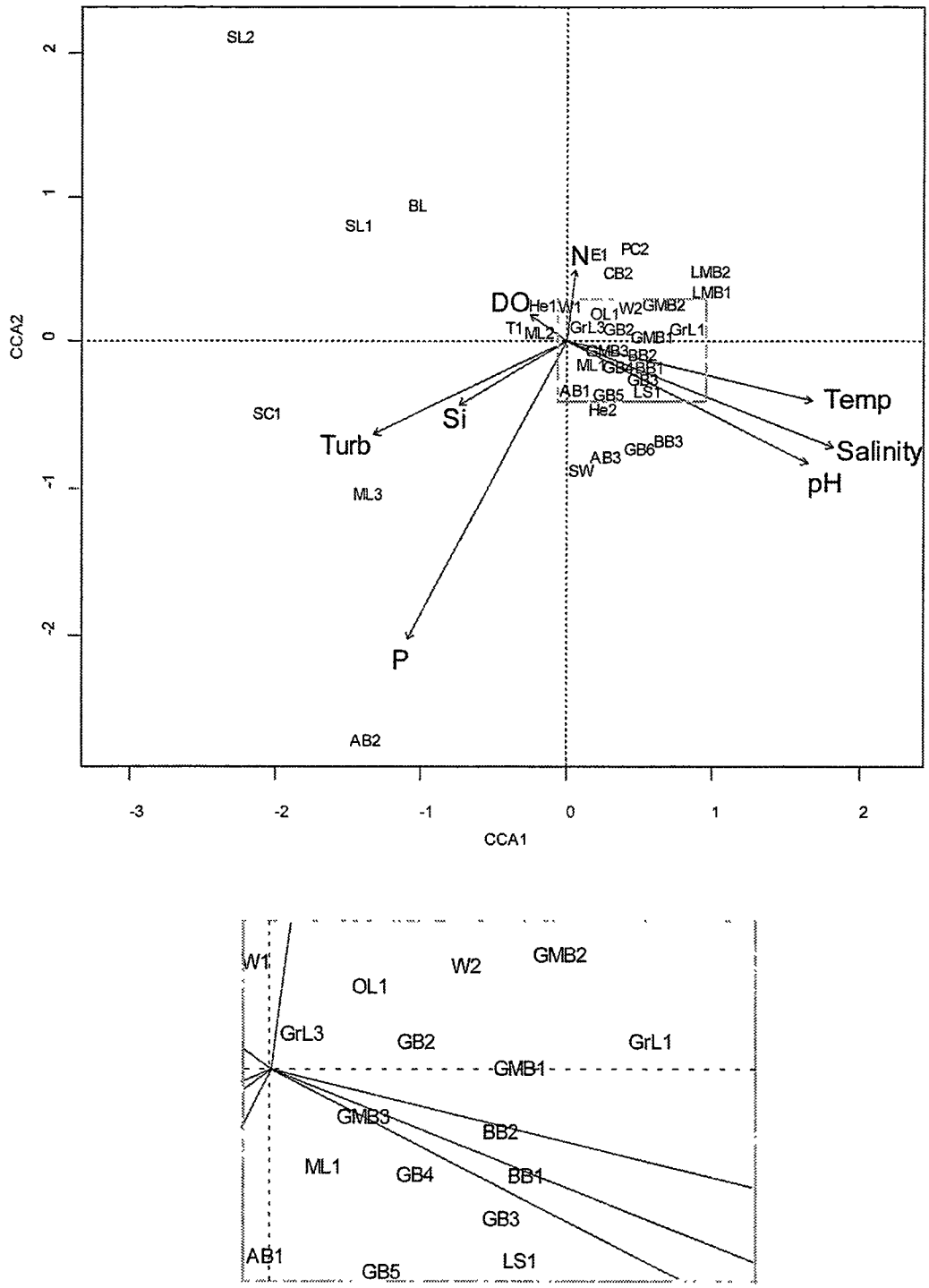


Figure 3.7: Canonical Correspondence Analysis of the Tasmanian dataset with all environmental variables. Sites displayed. Boxed region in the upper panel expanded below. Note: DO = dissolved oxygen, N = nitrate/nitrite, P = phosphate, Si = silicate, Temp = temperature, Turb = turbidity. See Appendix 1 for site names.

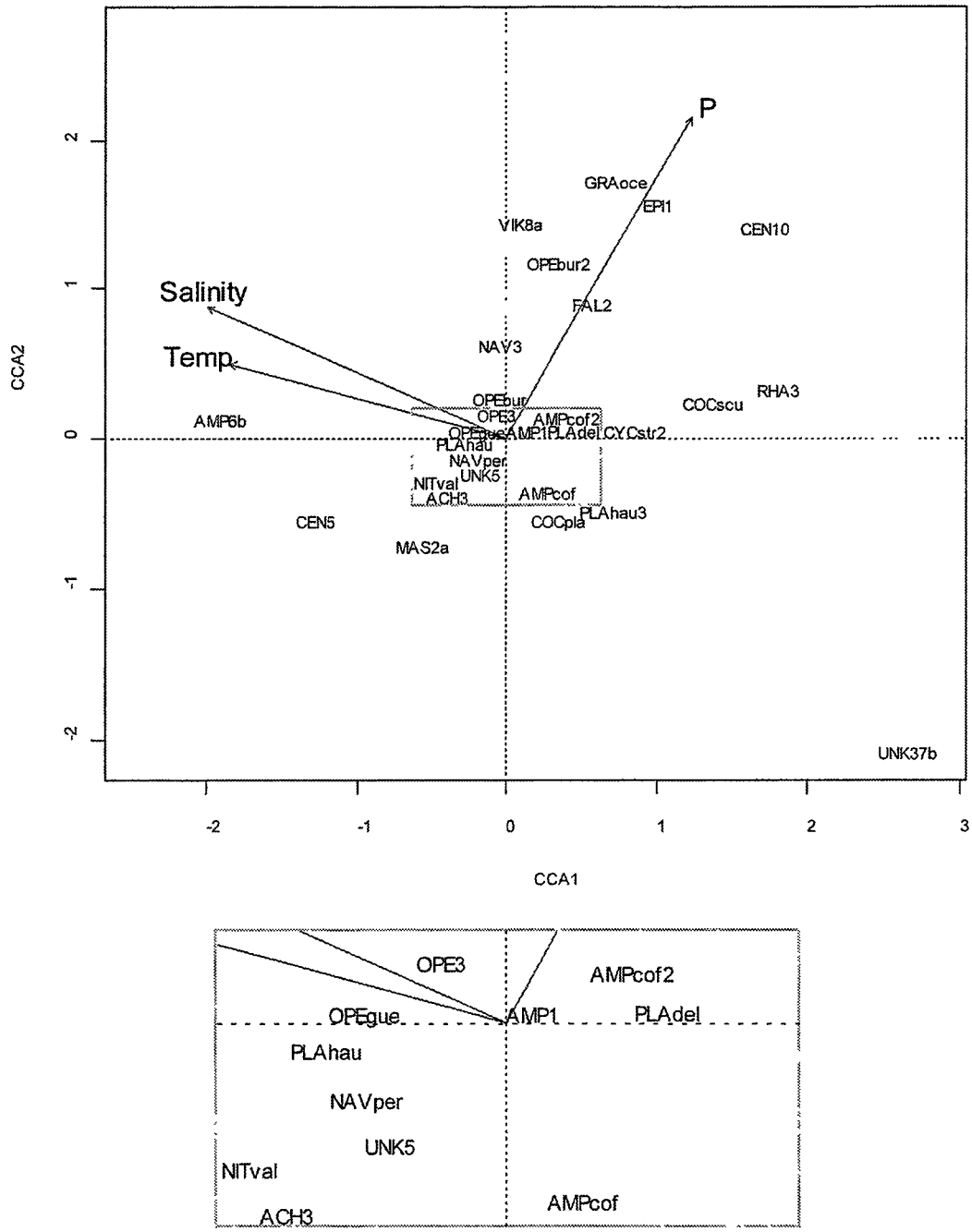


Figure 3.8: Canonical Correspondence Analysis of the Tasmanian dataset with forward selected variables. Dominant species (i.e. species occurring with a maximum relative abundance ≥ 10% and occurring in ≥ 10 samples) displayed. Boxed region in the upper panel expanded below. Note: P = phosphate, Temp = temperature. See Appendix 2 for species names.

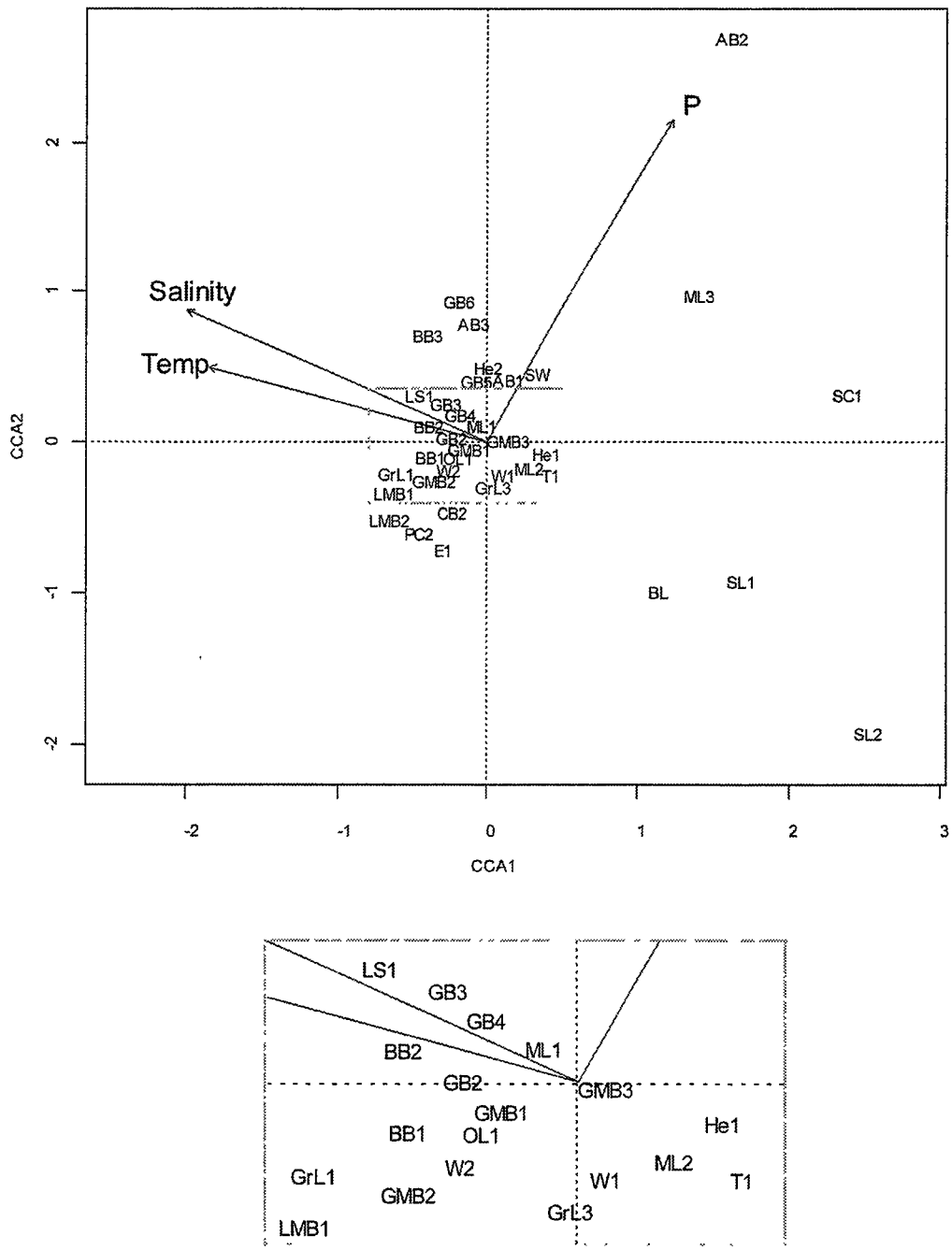


Figure 3.9: Canonical Correspondence Analysis of the Tasmanian dataset with forward selected variables. Sites displayed. Boxed region in the upper panel expanded below. Central area expanded. Note: P = phosphate, Temp = temperature. See Appendix 1 for site names.

Variance partitioning indicated that 12.8% of the variation in the diatom data was due to these environmental variables alone and the total interaction between them was 0.64% (Figure 3.10, Table 3.7). Salinity explained the most (4.67%), followed by temperature (4.17%) and phosphate (3.96%). The greatest interaction occurred between salinity and the other variables (0.57%).

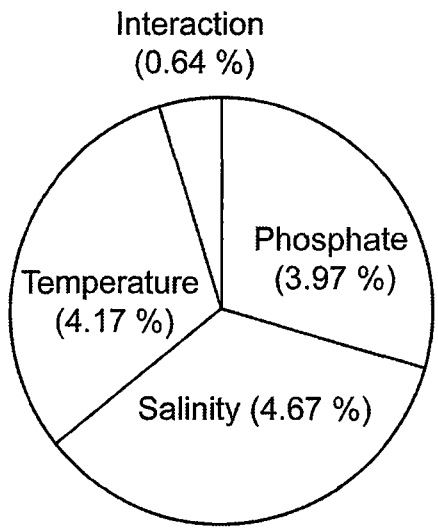


Figure 3.10: A summary of variance partitioning of the independent, significant explanatory variables in the Tasmanian dataset and their interaction.

Table 3.7: Variance partitioning results of the Tasmanian dataset. Note: $\sum$ = sum.

Environmental variable	Covariable	$\sum$ canonical eigenvalues	% variance explained	% interaction	p value
Phosphate	none	0.108	4.39	0.00	0.005
	salinity	0.099	4.03	0.36	0.01
	temperature	0.109	4.46	0.07	0.01
Salinity	none	0.129	5.24	0.00	<0.005
	phosphate	0.120	4.88	0.36	<0.005
	temperature	0.124	5.03	0.21	<0.005
Temperature	none	0.109	4.45	0.00	0.005
	phosphate	0.111	4.52	0.07	<0.005
	salinity	0.104	4.24	0.21	<0.005

(ii) Victorian dataset

CCA of the Victorian data indicated that the environmental variables explained 25.8% of the variation in the diatom data (Table 3.8). Silicate and phosphate were closest to axis 1, while turbidity and dissolved oxygen were closest to axis 2. Temperature and pH were correlated to each other and both axes (Figures 3.11-3.12).

Nitrate/nitrite, phosphate, salinity and turbidity explained independent portions of the variance in the diatom data (as determined by forward selection). CCA of these variables indicated that they explained 16.3% of the variation in the diatom data (Figures 3.13-3.14, Table 3.8).

Table 3.8: Canonical Correspondence Analysis of the Victorian dataset with all environmental variables and forward selected variables. Note: $\sum$ = sum.

Axis	1	2	3	4
All variables				
Eigenvalues	0.164	0.089	0.082	0.069
$\sum$ canonical eigenvalues	0.574			
$\sum$ all eigenvalues	2.225			
Forward selected variables only				
Eigenvalues	0.143	0.081	0.079	0.060
$\sum$ canonical eigenvalues	0.363			
$\sum$ all eigenvalues	2.225			

Variance partitioning indicated that 12.3% of the variation in the diatom data was due to these environmental variables alone and the total interaction between them was 2.05% (Figure 3.15, Table 3.9). Phosphate explained the most (3.57%), followed by salinity (3.39%), nitrate/nitrite (2.81%) and turbidity (2.57%). The greatest interaction occurred between nitrate/nitrite and the other variables (1.51%).

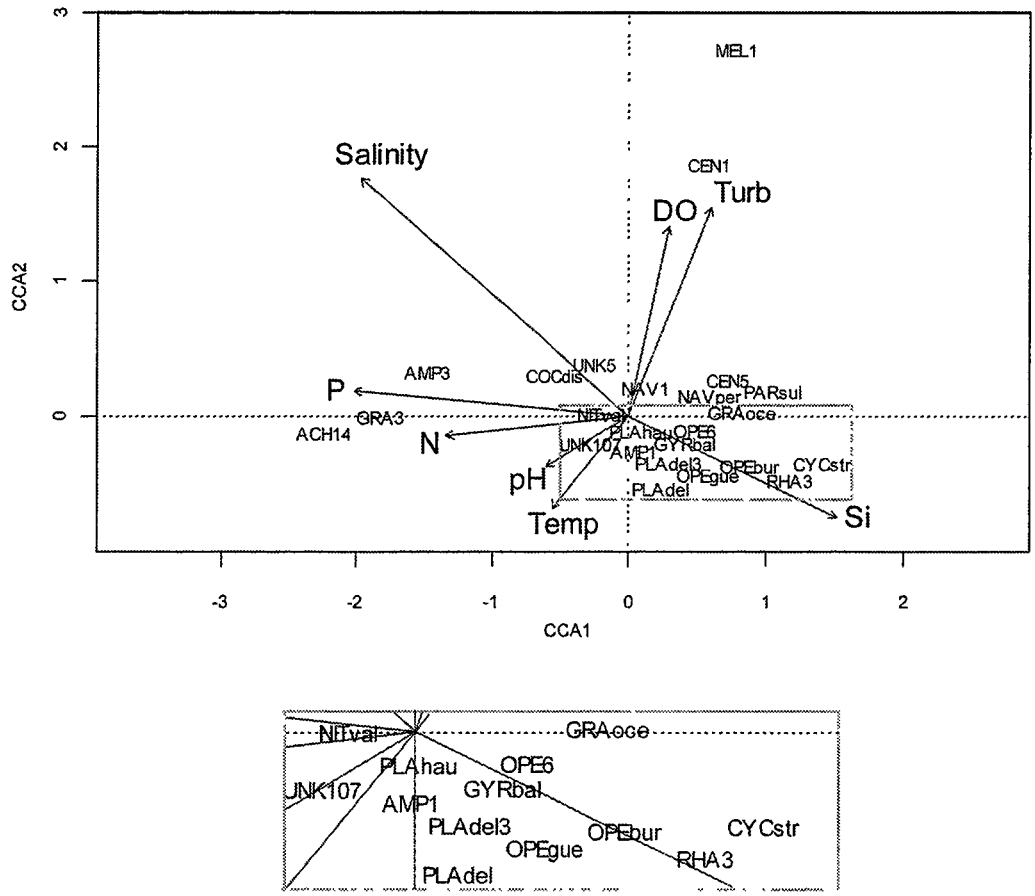


Figure 3.11: Canonical Correspondence Analysis of the Victorian dataset with all environmental variables. Dominant species (i.e. species occurring with a maximum relative abundance ≥ 10% and occurring in ≥ 10 samples) displayed. Boxed region in the upper panel expanded below. Note: DO = dissolved oxygen, N = nitrate/nitrite, P = phosphate, Si = silicate, Temp = temperature, Turb = turbidity. See Appendix 2 for species names.

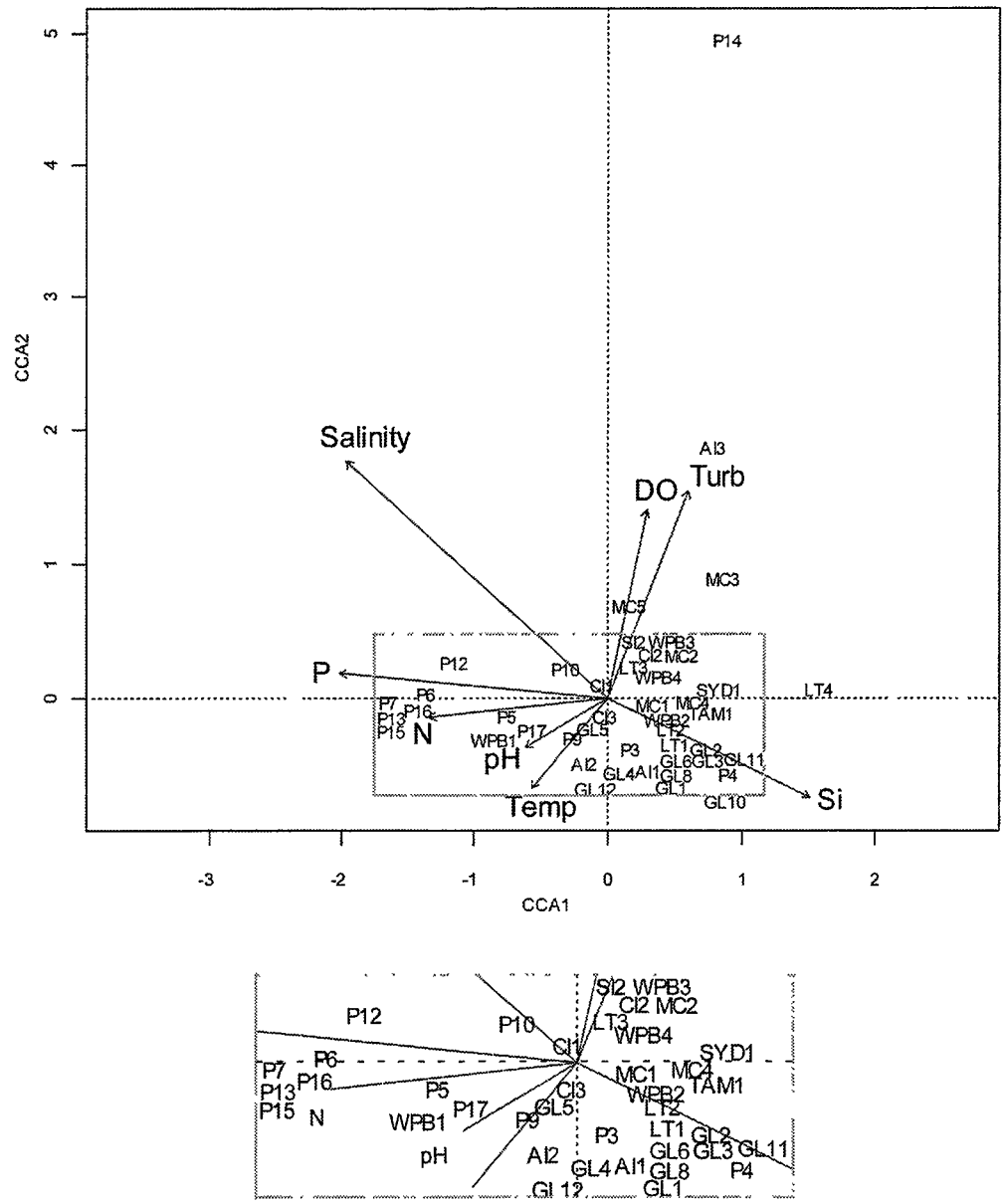


Figure 3.12: Canonical Correspondence Analysis of the Victorian dataset with all environmental variables. Sites displayed. Boxed region in the upper panel expanded below. Note: DO = dissolved oxygen, N = nitrate/nitrite, P = phosphate, Si = silicate, Temp = temperature, Turb = turbidity. See Appendix 1 for site names.

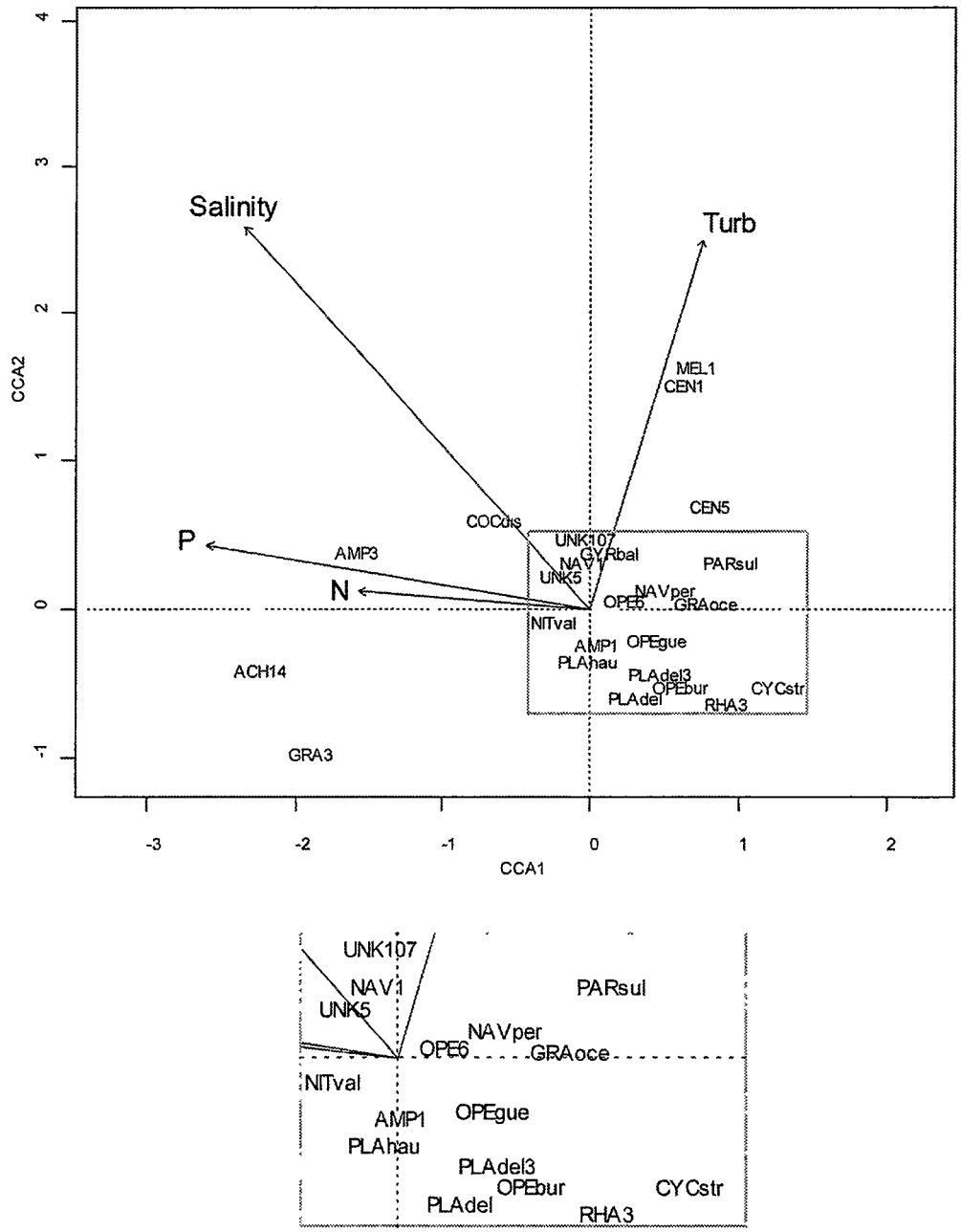


Figure 3.13: Canonical Correspondence Analysis of the Victorian dataset with forward selected variables. Dominant species (i.e. species occurring with a maximum relative abundance ≥ 10% and occurring in ≥ 10 samples) displayed. Boxed region in the upper panel expanded below. Central area expanded below. Note: N = nitrate/nitrite, P = phosphate, Turb = turbidity. See Appendix 2 for species names.

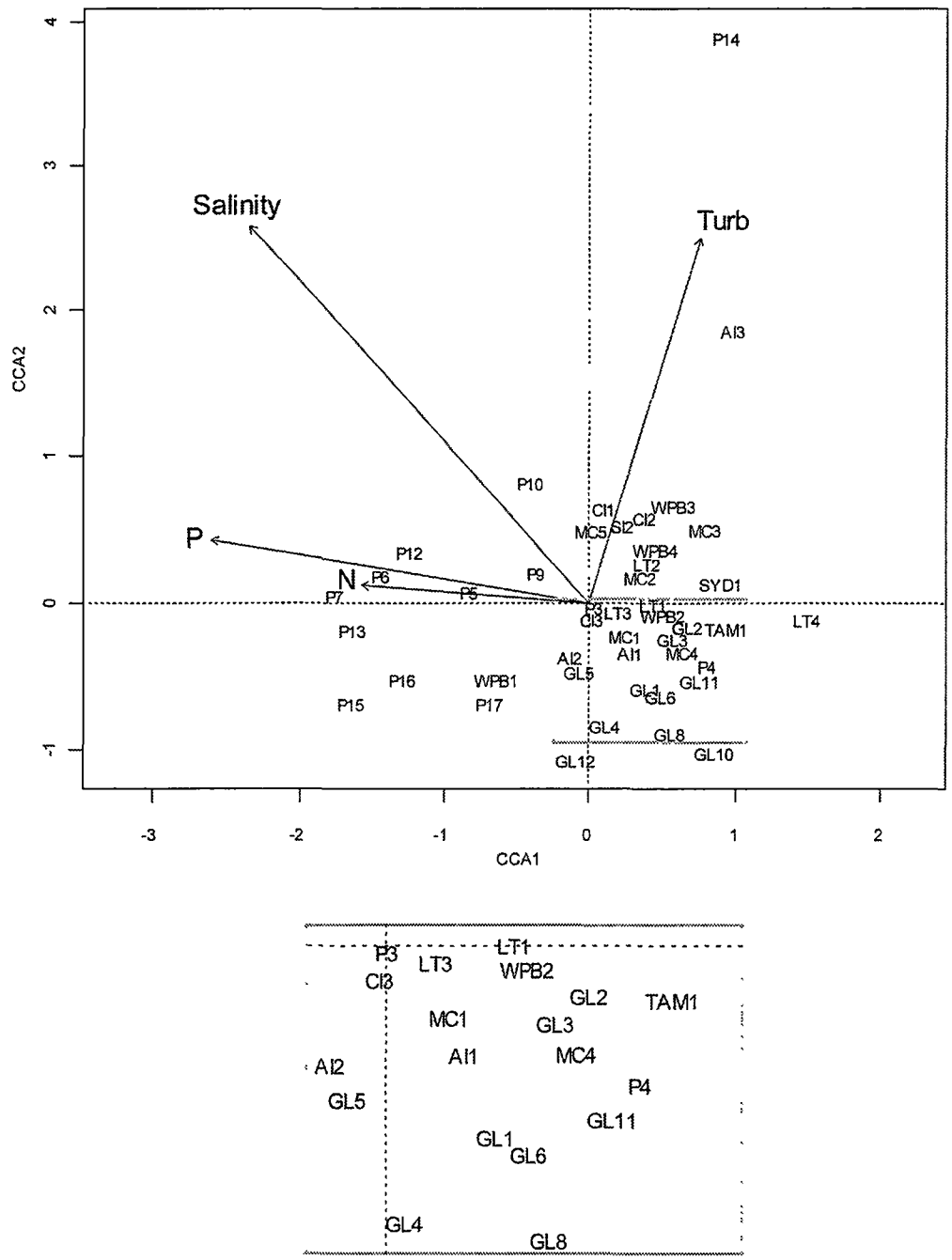


Figure 3.14: Canonical Correspondence Analysis of the Victorian dataset with forward selected variables. Sites displayed. Boxed region in the upper panel expanded below. Note: N = nitrate/nitrite, P = phosphate, Turb = turbidity. See Appendix 1 for site names.

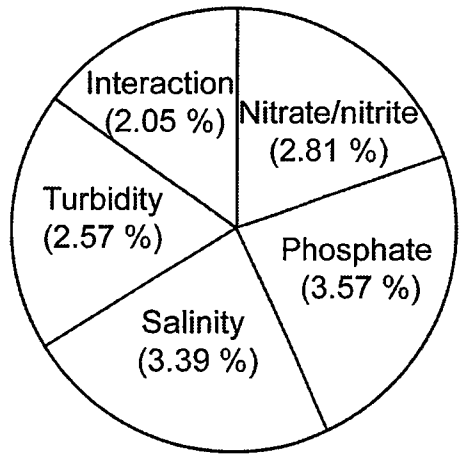


Figure 3.15: A summary of variance partitioning of the independent, significant explanatory variables in the Victorian dataset and their interaction.

Table 3.9: Variance partitioning results of the Victorian dataset. Note: $\sum$ = sum.

Environmental variable	Covariable	$\sum$ canonical eigenvalues	% variance explained	% interaction	p value
Nitrate/nitrite	none	0.096	4.32	0.00	<0.005
	phosphate	0.081	3.62	0.70	0.01
	salinity	0.100	4.50	0.18	<0.005
	turbidity	0.111	4.95	0.63	<0.005
Phosphate	none	0.107	4.80	0.00	<0.005
	nitrate/nitrite	0.091	4.10	0.70	<0.005
	salinity	0.010	4.49	0.31	<0.005
	turbidity	0.112	5.02	0.22	<0.005
Salinity	none	0.087	3.89	0.00	<0.005
	nitrate/nitrite	0.907	4.07	0.18	<0.005
	phosphate	0.080	3.58	0.31	<0.005
	turbidity	0.087	3.90	0.01	0.005
Turbidity	none	0.071	3.43	0.00	0.027
	nitrate/nitrite	0.090	4.06	0.63	0.005
	phosphate	0.081	3.65	0.22	0.005
	salinity	0.076	3.42	0.01	0.005

(iii) Combined Tasmanian and Victorian dataset

CCA of the combined Tasmanian and Victorian datasets indicated that the environmental variables (including latitude and longitude) explained 22.6% of the variation in the diatom data (Table 3.10). Figures 3.16 and 3.17 illustrate the influence of latitude and longitude on the diatom and environmental data, with longitude correlated to axis 1 and latitude closely correlated to axis 2. Nitrate/nitrite, pH and silicate were closely correlated to axis 1, dissolved oxygen was closest to axis 2, while salinity, phosphate, temperature and pH were correlated to both axes.

Latitude, longitude, nitrate/nitrite, phosphate, salinity and turbidity explained independent portions of the variance in the diatom data (as determined by forward selection) in the combined dataset. CCA of these variables indicated they explained 16.2% of the variation in the diatom data (Figures 3.18-3.19, Table 3.10).

Table 3.10: Canonical Correspondence Analysis of the combined dataset on all the environmental variables (including latitude and longitude) and forward selected variables only (i.e. latitude, longitude, nitrate/nitrite, phosphate, salinity and turbidity). Note: $\sum$ = sum.

Axis	1	2	3	4
All variables				
Eigenvalues	0.123	0.109	0.056	0.045
$\sum$ canonical eigenvalues	0.539			
$\sum$ all eigenvalues	2.392			
Forward selected variables				
Eigenvalues	0.122	0.107	0.052	0.041
$\sum$ canonical eigenvalues	0.387			
$\sum$ all eigenvalues	2.392			

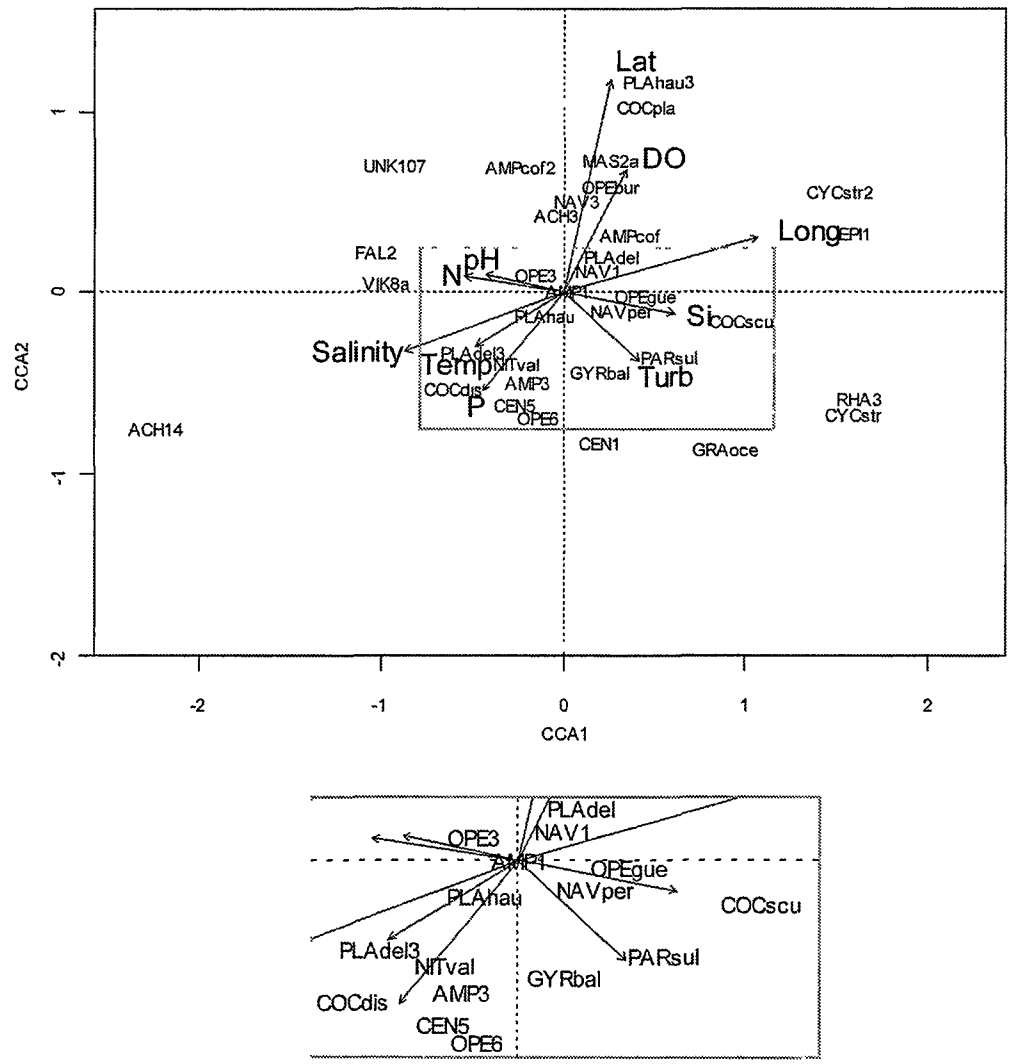


Figure 3.16: Canonical Correspondence Analysis of the combined dataset with all environmental variables (latitude and longitude included). Dominant species (i.e. species occurring with a maximum relative abundance ≥ 10% and occurring in ≥ 10 samples) displayed. Boxed region in the upper panel expanded below. Note: DO = dissolved oxygen, Lat = latitude, Long = longitude, N = nitrate/nitrite, P = phosphate, Si = silicate, Temp = temperature, Turb = turbidity. See Appendix 2 for species names.

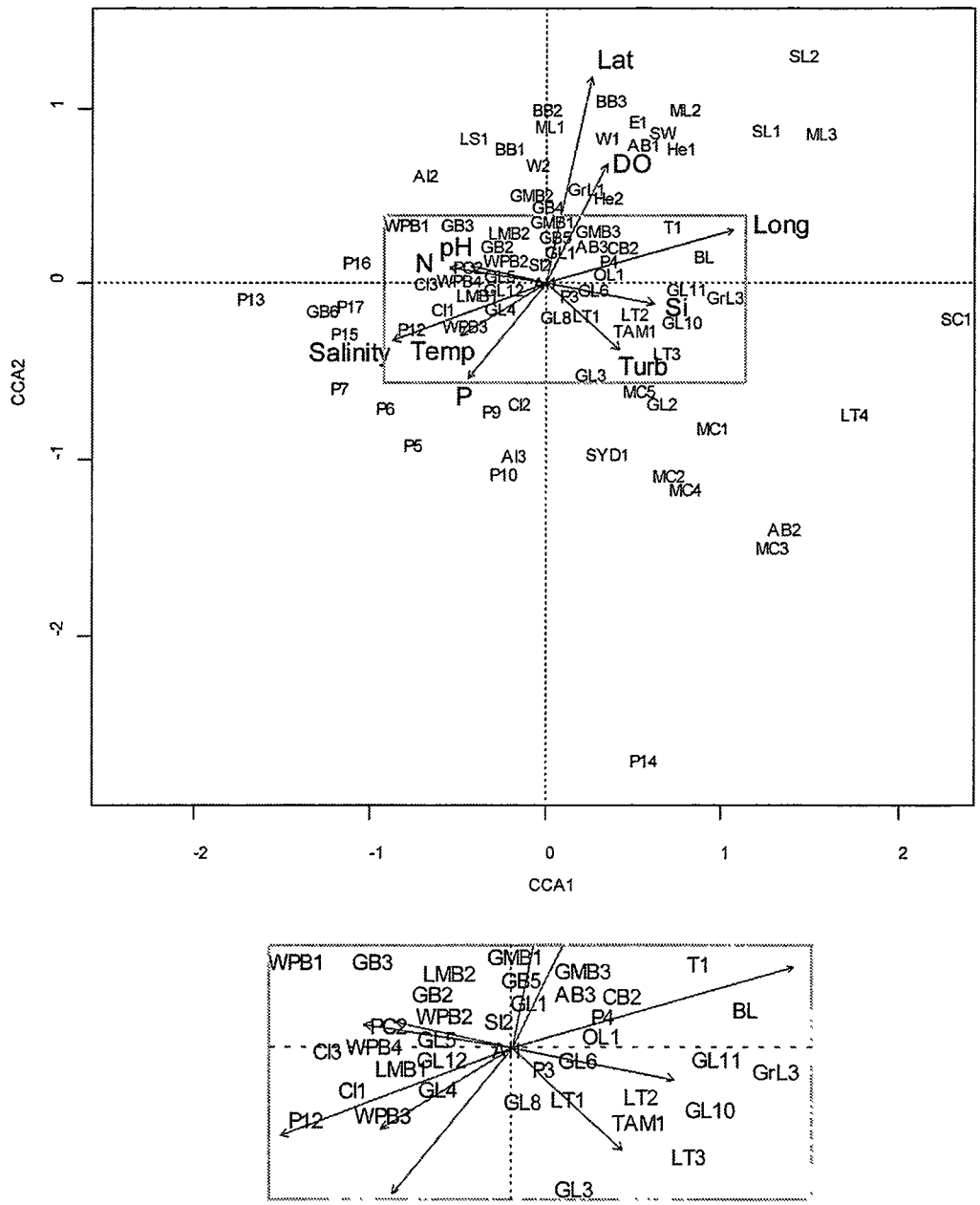


Figure 3.17: Canonical Correspondence Analysis of the combined dataset with all environmental variables (latitude and longitude included). Sites displayed. Boxed region in the upper panel expanded below. Note: DO = dissolved oxygen, Lat = latitude, Long = longitude, N = nitrate/nitrite, P = phosphate, Si = silicate, Temp = temperature, Turb = turbidity. See Appendix 1 for site names.

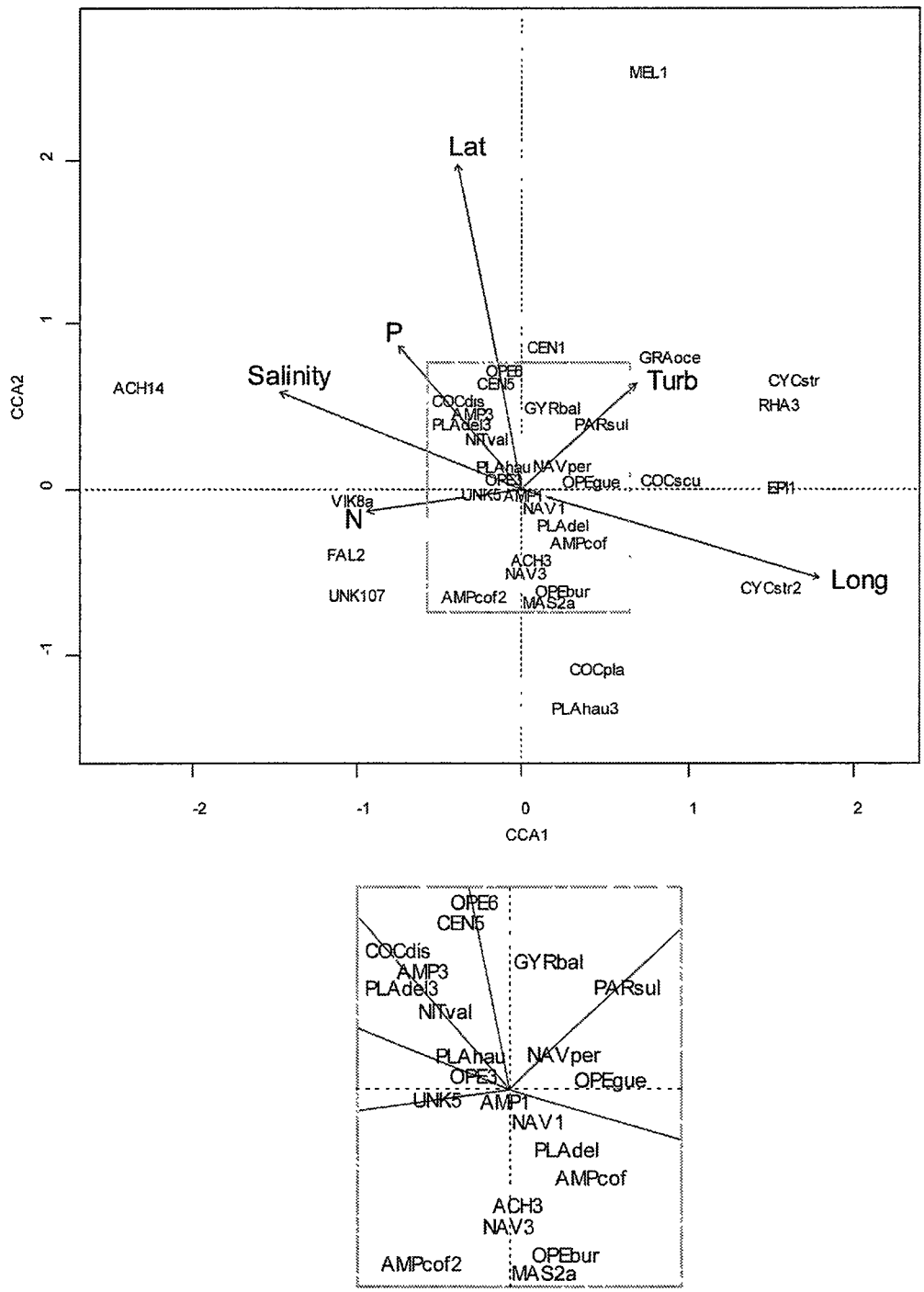


Figure 3.18: Canonical Correspondence Analysis of the combined dataset with forward selected variables (latitude and longitude included). Dominant species (i.e. species occurring with a maximum relative abundance ≥ 10% and occurring in ≥ 10 samples) displayed. Boxed region in the upper panel expanded below. Note: Lat = latitude, Long = longitude, N = nitrate/nitrite, P = phosphate, Turb = turbidity. See Appendix 2 for species names.

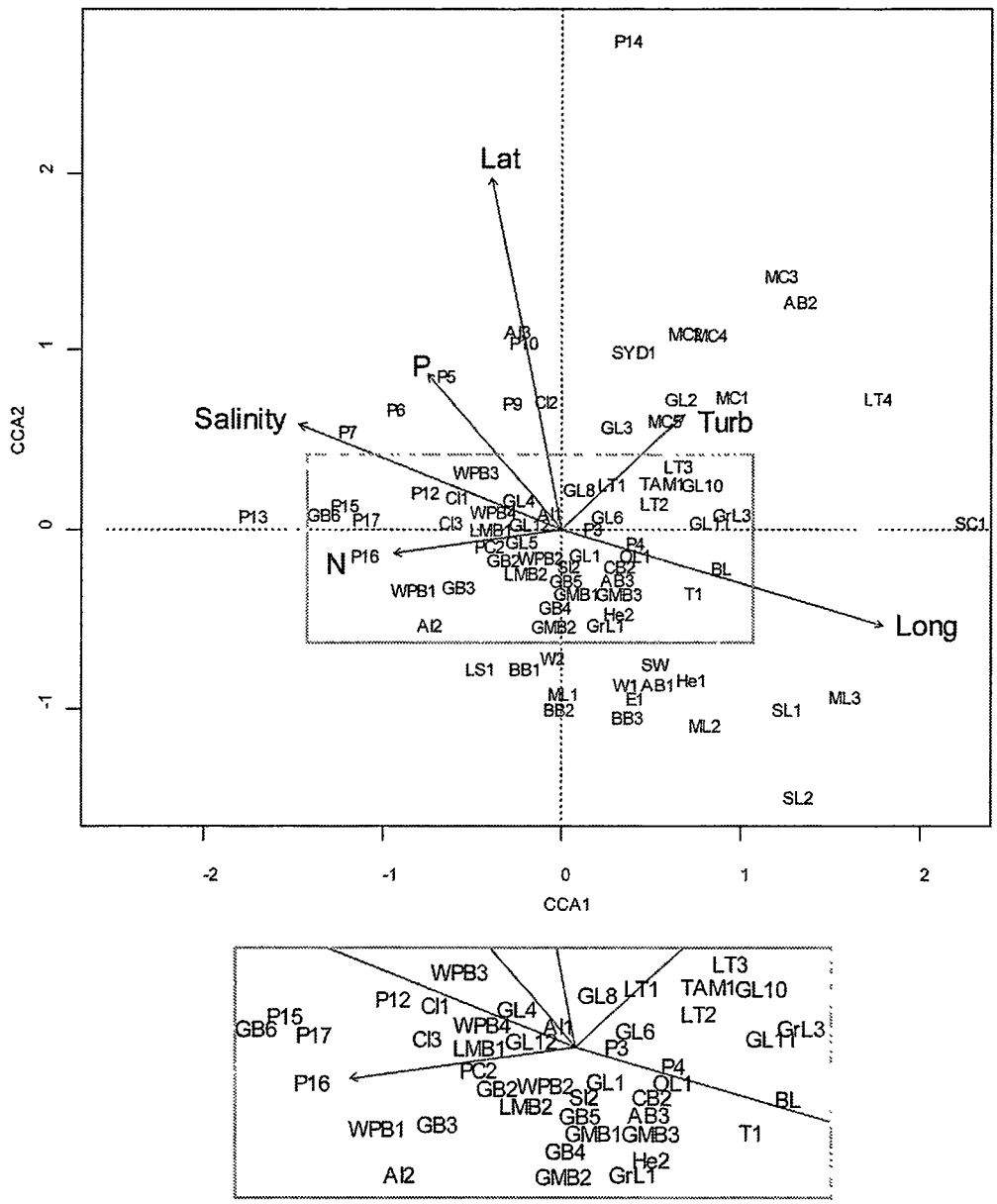


Figure 3.19: Canonical Correspondence Analysis of the combined dataset with forward selected variables (latitude and longitude included). Sites displayed. Boxed region in the upper panel expanded below. Note: DO = dissolved oxygen, Lat = latitude, Long = longitude, N = nitrate/nitrite, P = phosphate, Turb = turbidity. See Appendix 1 for site names.

Variance partitioning indicated that 9.37% of the variation in the diatom data was due to these environmental variables alone and the total interaction between them was 3.94% (Figure 3.20, Table 3.11). Latitude explained the most amount of variation (3.73%), followed by salinity (1.76%), phosphate (1.45%), longitude (1.15%), turbidity (0.67%) and nitrate/nitrite (0.61%). The greatest interaction occurred between longitude and the other variables (2.90%).

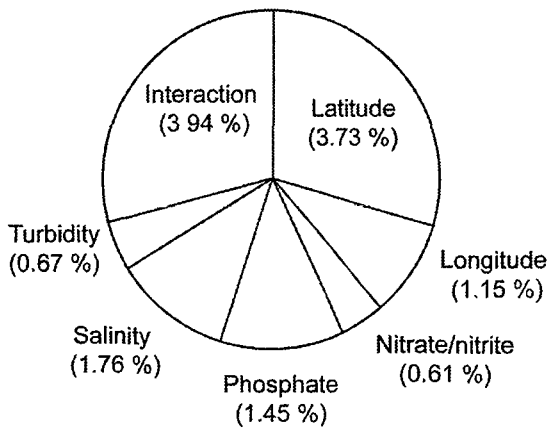


Figure 3.20: A summary of variance partitioning of the independent, significant explanatory variables in the combined dataset and their interaction.

Table 3.11: Variance partitioning results of the combined Tasmanian and Victorian datasets (including latitude and longitude). Note: $\sum$ = sum.

Environmental variable	Covariable	$\sum$ canonical eigenvalues	% variance explained	% interaction	p value
Latitude	none	0.090	3.77	0.00	<0.005
	longitude	0.096	4.00	0.23	<0.005
	nitrate/nitrite	0.090	3.78	0.01	<0.005
	phosphate	0.087	3.65	0.12	<0.005
	salinity	0.089	3.73	0 04	<0.005
	turbidity	0.090	3.77	0.00	<0.005
Longitude	none	0.097	4.05	0.00	<0.005
	latitude	0.102	4.28	0.23	<0.005
	nitrate/nitrite	0.072	3.01	1.04	<0.005
	phosphate	0.085	3.57	0.48	<0.005
	salinity	0.078	3.24	0.81	<0.005
	turbidity	0.105	4.39	0.34	<0.005
Nitrate/nitrite	none	0.060	2.49	0.00	<0.005
	latitude	0.060	2.50	0.01	<0.005
	longitude	0.035	1.45	1.04	<0.005
	phosphate	0.054	2.24	0.25	<0.005
	salinity	0.063	2.63	0.14	<0.005
	turbidity	0.070	2.93	0 44	<0 005
Phosphate	none	0.064	2.67	0.00	<0.005
	latitude	0.061	2.55	0.12	<0.005
	longitude	0.052	2.19	0.48	<0.005
	nitrate/nitrite	0.058	2 42	0.25	<0.005
	salinity	0.062	2.58	0.09	<0.005
	turbidity	0.071	2 95	0.28	<0.005
Salinity	none	0.069	2.87	0.00	<0.005
	latitude	0 068	2.83	0.04	<0.005
	longitude	0.049	2.06	0.81	<0.005
	nitrate/nitrite	0.072	3.01	0.14	<0.005
	phosphate	0.066	2 78	0.09	<0.005
	turbidity	0.068	2.84	0.03	<0.005
Turbidity	none	0.042	1.76	0.00	<0.005
	latitude	0.042	1.76	0.00	<0.005
	longitude	0.050	2.10	0.34	<0.005
	nitrate/nitrite	0.053	2.20	0.44	<0.005
	phosphate	0.049	2.04	0.28	<0.005
	salinity	0.041	1.73	0.03	0.01

To investigate the influence of the measured environmental variables only, the above multivariate steps were repeated without latitude and longitude. CCA of the combined Tasmanian and Victorian datasets indicated that the environmental variables explained 16.3% of the variation in the diatom data (Table 3.12). Nitrate/nitrite was correlated to axis 1, while the remaining environmental variables were correlated to both axes 1 and 2 (Figure 3.21-3.22).

Nitrate/nitrite, phosphate, salinity and turbidity explained independent portions of the variance in the diatom data (as determined by forward selection) in the combined dataset. CCA of these variables indicated that they explained 10.0% of the variation in the diatom data (Figures 3.23-3.24, Table 3.12).

Table 3.12: Canonical Correspondence Analysis of the combined dataset with all the environmental variables (excluding latitude and longitude) and forward selected variables only (i.e. nitrate/nitrite, phosphate, salinity and turbidity). Note: $\sum$ = sum.

Axis	1	2	3	4
All sites				
Eigenvalues	0.106	0.062	0.054	0.044
$\sum$ canonical eigenvalues	0.390			
$\sum$ all eigenvalues	2.392			
Forward selected variables				
Eigenvalues	0.103	0.054	0.043	0.038
$\sum$ canonical eigenvalues	0.238			
$\sum$ all eigenvalues	2.392			

Variance partitioning indicated that 7.29% of the variation in the diatom data was due to these environmental variables alone and the total interaction between them was 1.25% (Figure 3.25, Table 3.13). Salinity explained the most amount of variation (2.59%), followed by phosphate (2.04%), nitrate/nitrite (1.66%) and turbidity (1.00%). The most amount of interaction occurred between nitrate/nitrite and the other variables (0.63%).

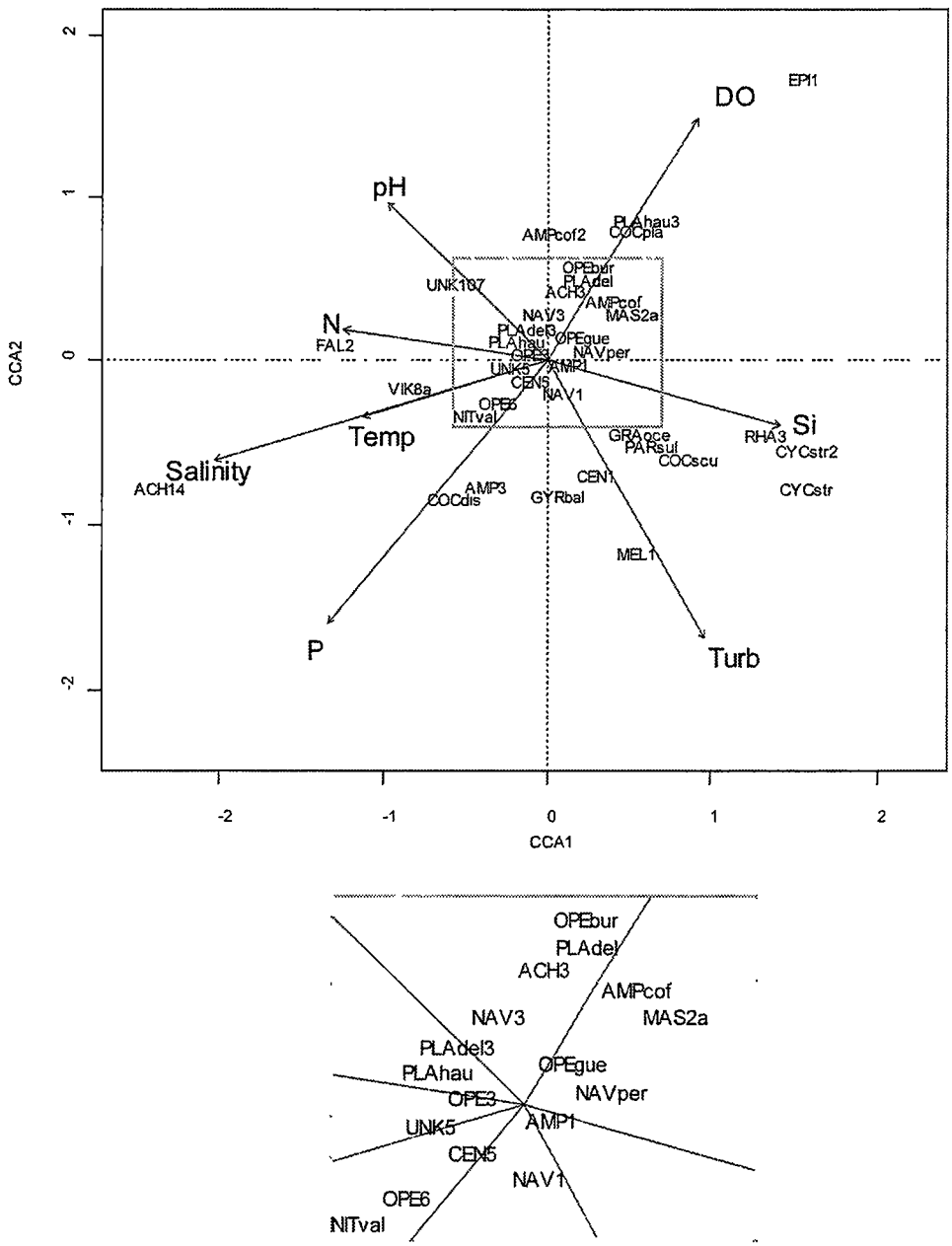


Figure 3.21: Canonical Correspondence Analysis of the combined dataset with all environmental variables (latitude and longitude excluded). Dominant species (i.e. species occurring with a maximum relative abundance ≥ 10% and occurring in ≥ 10 samples) displayed. Boxed region in the upper panel expanded below. Note: DO = dissolved oxygen, N = nitrate/nitrite, P = phosphate, Si = silicate, Temp = temperature, Turb = turbidity. See Appendix 2 for species names.

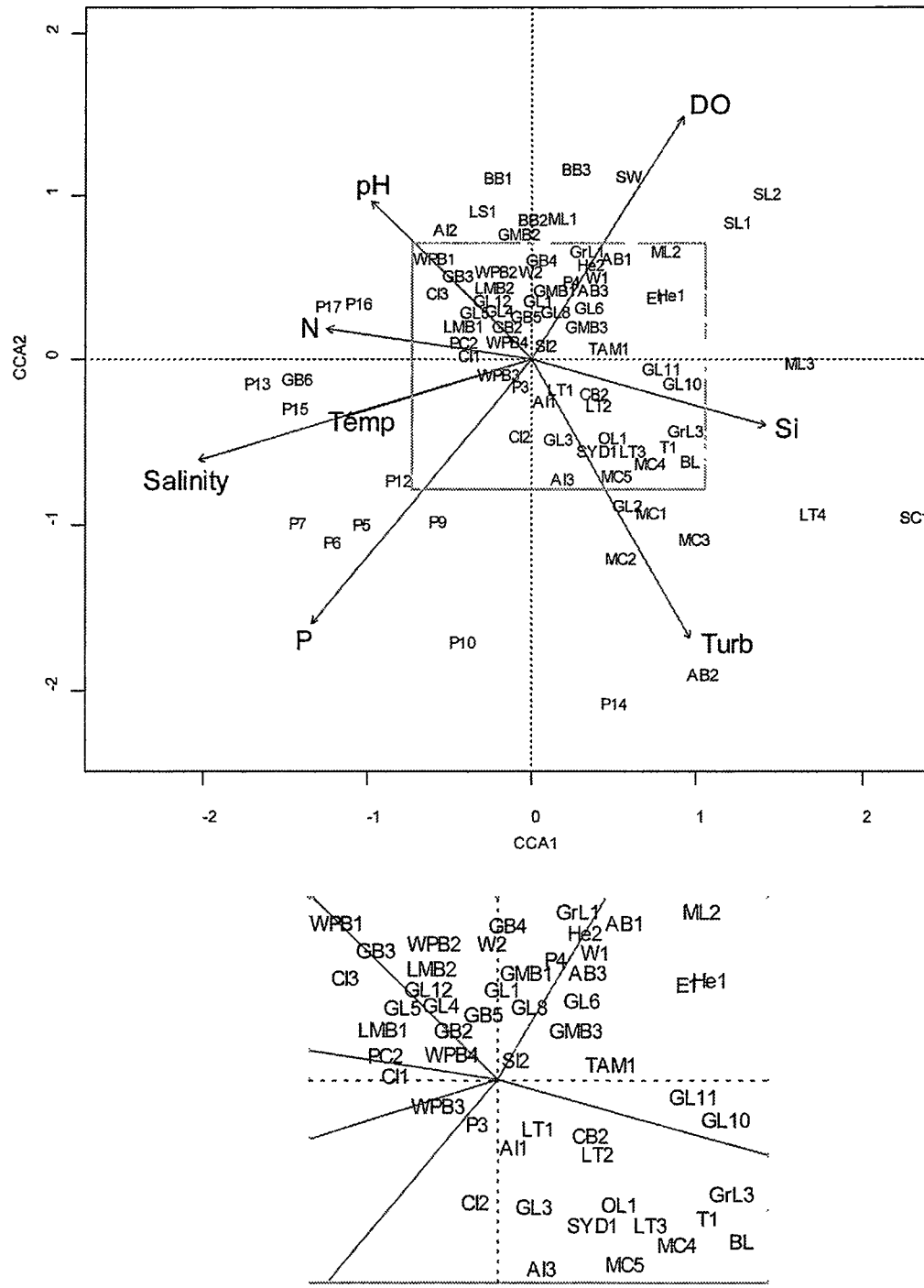


Figure 3.22: Canonical Correspondence Analysis of the combined dataset with all environmental variables (latitude and longitude excluded). Sites displayed. Boxed region in the upper panel expanded below. Note: DO = dissolved oxygen, N = nitrate/nitrite, P = phosphate, Si = silicate, Temp = temperature, Turb = turbidity. See Appendix 1 for site names.

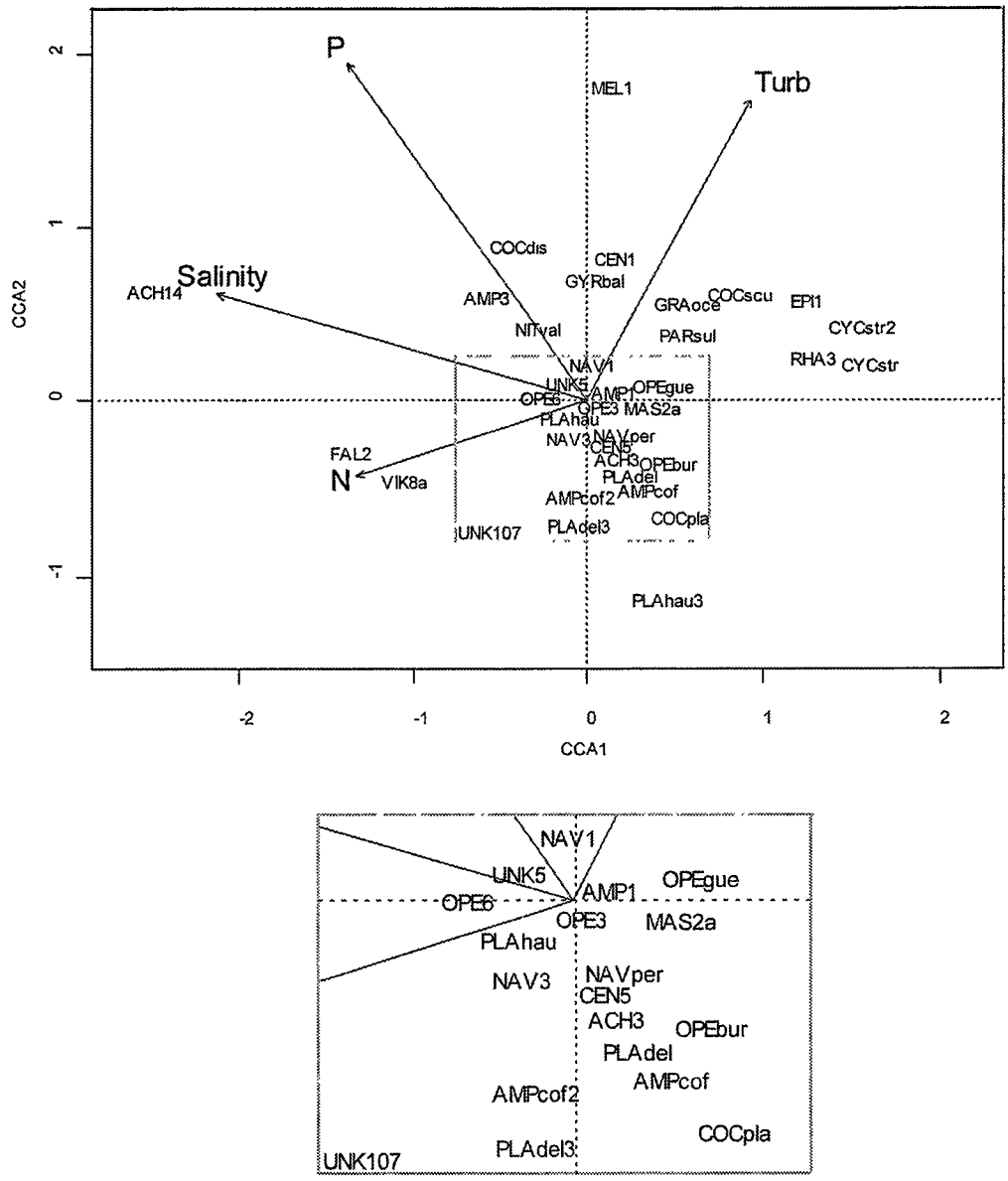


Figure 3.23: Canonical Correspondence Analysis of the combined dataset with forward selected variables (latitude and longitude excluded). Dominant species (i.e. species occurring with a maximum relative abundance ≥ 10% and occurring in ≥ 10 samples) displayed. Boxed region in the upper panel expanded below. Note: N = nitrate/nitrite, P = phosphate, Turb = turbidity. See Appendix 2 for species names.

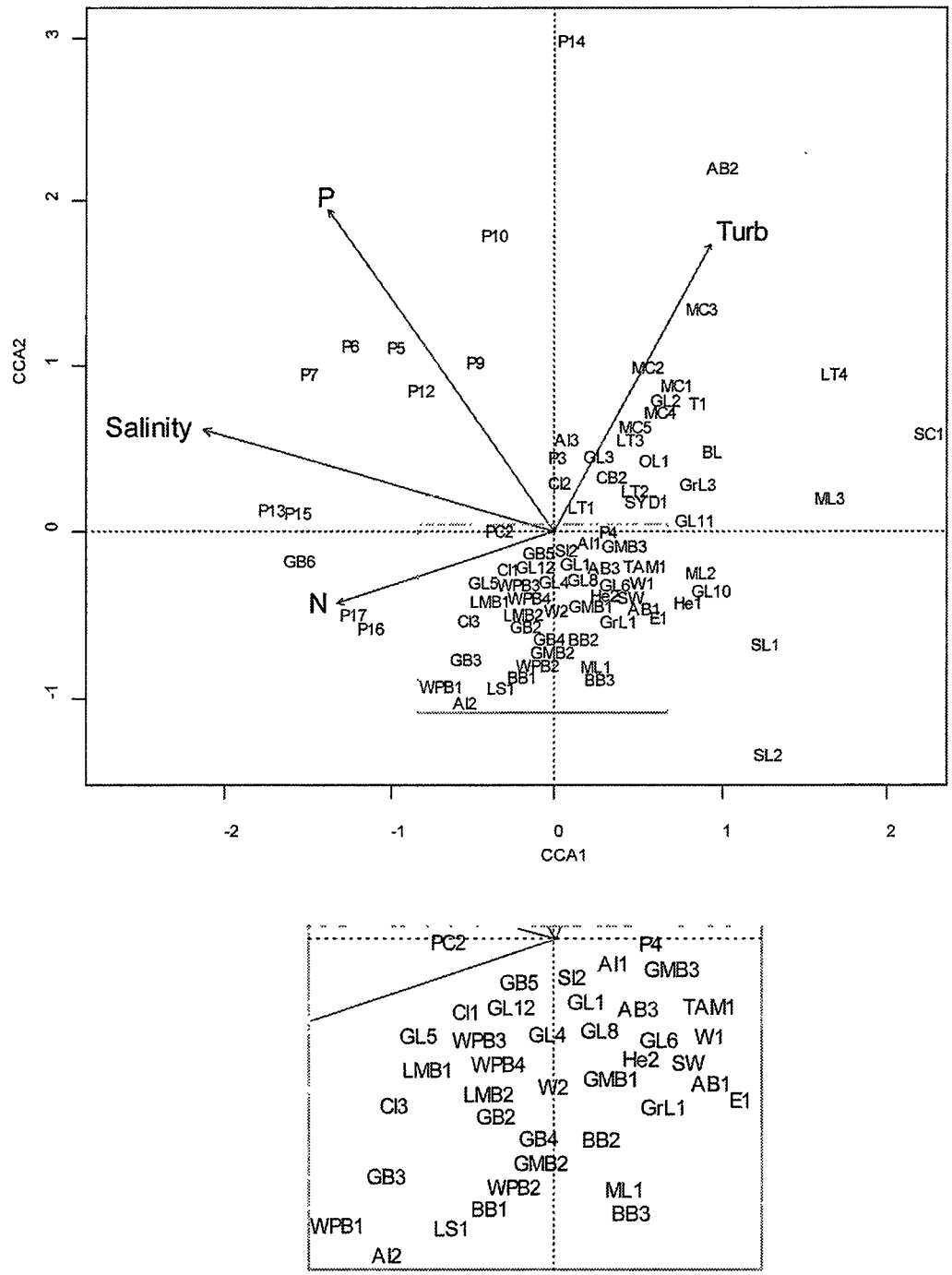


Figure 3.24: Canonical Correspondence Analysis of the combined dataset with forward selected variables (latitude and longitude excluded). Sites displayed. Boxed region in the upper panel expanded below. Note: N = nitrate/nitrite, P = phosphate, Turb = turbidity. See Appendix 1 for site names.

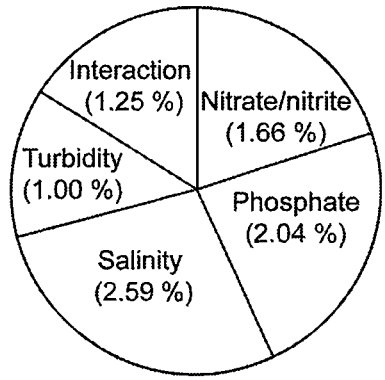


Figure 3.25: A summary of variance partitioning of the independent, significant explanatory variables in the combined dataset and their interaction.

Table 3.13: Variance partitioning results of the combined dataset. Note: ∑ = sum.

Environmental variable	Covariable	∑ canonical eigenvalues	% variance explained	% interaction	p value
Nitrate/nitrite	none	0.059	2.49	0.00	<0.005
	phosphate	0.054	2.24	0.25	<0.005
	salinity	0.063	2.63	0.14	<0.005
	turbidity	0.070	2.93	0.44	<0.005
Phosphate	none	0.064	2.67	0.00	<0.005
	nitrate/nitrite	0.058	2.42	0.25	<0.005
	salinity	0.062	2.57	0.10	<0.005
	turbidity	0.071	2.95	0.28	<0.005
Salinity	none	0. 069	2.87	0.00	<0.005
	nitrate/nitrite	0. 066	2.77	0.10	<0.005
	phosphate	0. 072	3.01	0.14	<0.005
	turbidity	0. 068	2.83	004	<0.005
Turbidity	none	0.042	1.76	0.00	<0.005
	nitrate/nitrite	0.053	2.20	0.44	<0.005
	phosphate	0.049	2.04	0.28	<0.005
	salinity	0.041	1.72	0.04	0.01

(iv) Summary

The relatively large proportion of variance in the diatom data explained by latitude illustrates the influence of location on diatom species of southeast Australian coastal water bodies and indicates the datasets should be treated separately. Phosphate, salinity and temperature explained independent portions of the variance in diatom species distribution in the Tasmanian dataset, while nitrate/nitrite, phosphate, salinity and turbidity explained independent portions of the variance in diatom species distribution in the Victorian dataset. Latitude, longitude, nitrate/nitrite, phosphate, salinity and turbidity explained independent portions of the variance in diatom species distribution when the Tasmanian and Victorian datasets were combined.

3.3.4 Species optima and tolerances

Simple weighted averaging (WA) was used to determine species optima and tolerances for phosphate, salinity and temperature for the Tasmanian dataset, and for nitrate/nitrite, phosphate, salinity and turbidity for the Victorian dataset. Optima and tolerances (see Chapter 1, Figure 1.1 for definitions) for all species are outlined in Appendix 4. Tables 3.14 and 3.15 list the optima and tolerances of the most widespread and abundant taxa in the Tasmanian and Victorian datasets respectively. Figures 3.26-3.32 illustrate the distribution and abundance of the dominant diatom species along these environmental gradients (i.e. species with ≥ 10 % maximum relative abundance and occurring in ≥ 10 samples, which corresponds to the species in the previous ordination plots).

Table 3.14: Most widespread (i.e. occurring in ≥ 30 sites) and abundant (i.e. occurring with ≥ 10% relative abundance) diatom taxa in the Tasmanian reference dataset and their inferred optima and tolerances. Note: P opt = phosphate optimum, P tol = phosphate tolerance, S opt = salinity optimum, S tol = salinity tolerance, T opt = temperature optimum, T tol = temperature tolerance.

Name	Species code	P opt µg P L^{-1}	P tol µg P L^{-1}	S opt ppt	S tol ppt	T opt °C	T tol °C
Achnanthes angustata	OPE3	5.8	0.7	19.7	1.5	15.8	2.4
Achnanthes brevipes var. *intermedia*	EPI1	10.9	0.9	30.6	0.1	15.0	0.9
Actinocyclus subtilis	CEN10	14.3	2.0	18.4	0.7	15.6	1.3
Amphora sp. 3	AMP6b	3.6	0.9	36.3	0.6	17.3	1.7
Amphora coffeaeformis	AMPcof	4.8	0.8	23.7	0.7	15.1	2.2
Catenula adherens	AMP1	5.2	0.8	24.6	0.8	15.5	2.0
Cocconeis peltoides var. 1	ACH3	4.2	0.5	22.1	0.6	14.9	2.3
Cocconeis peltoides	DIP7	4.9	0.6	25.2	0.4	15.9	1.8
Cocconeis placentula	COCpla	4.9	0.7	17.7	1.2	15.3	2.4
Cocconeis placentula var. *euglypta*	COCplae	4.7	0.7	21.6	0 4	15.7	2.2
Cocconeis scutellum	COCscu	7.8	1.2	16.9	1.2	14.4	2.5
Cyclotella choctawhatceeana	CYCstr2	6.4	1.3	17.9	1.5	14.8	2.0
Diatomella cf. *balfouriana*	UNK37b	4.7	0.9	8.1	0.7	12.9	2.4
Diploneis cf. *domblitlensis* var. 1	FAL2	6 9	1 0	22.6	1.4	13.8	2.1
Fragilaria ellipta agg.	CEN5	4 0	0.6	25.8	0.3	17.4	2.0
Grammatophora oceanica	GRAoce	10.2	2.2	21.2	1.2	15.2	1.8
Lunella cf. *bisecta* var. *1*	AMP6b	3.6	0.9	36.3	0.6	17.3	1.7
Mastogloia pusilla	MAS2a	2.9	0.5	31.7	0.2	14.6	0.6
Melosira lineata var. *juergensis*	UNK43	23.6	3.4	5.4	4.6	15.6	1.1
Navicula perminuta	NAVper	4.5	0.8	24.9	0.7	15.3	2.0
Navicula recens	NAV7	4.2	0.8	26.5	0.6	15.2	2 0
Navicula salinarum var. *salinarum*	NAV3	6 0	1.1	23.1	1.5	15.3	1.9
Nitzschia cf. *valdestriata*	NITval	4.2	0.9	26 9	0.5	15.6	2.0
Opephora guenter grassii	OPEgue	5.1	0.9	23.3	1.1	15.6	1.7
Opephora pacifica	OPEbur/ OPEbur2	5.7	0.9	26.1	0.6	15.6	1.9
Rhopalodia acuminata	RHA3	8.0	1.6	14.9	1.5	13.6	2.4
Planothidium delicatulum agg.	PLAdel	5.8	0.9	23.5	0.7	15.2	1.9
Planothidium hauckianum agg.	PLAhau	4.6	0.7	21.6	1.5	15.3	1.9
Trachyspenia australis var. *australis*	VIK8a	7.1	0.5	31.6	0.3	13.7	0.6

Table 3.15: Most widespread (i.e. occurring in ≥ 30 sites) and dominant (i.e. occurring with ≥ 10% relative abundance) diatom taxa in the Victorian reference dataset and their inferred optima and tolerances. Note: N opt = nitrate/nitrite optimum, N tol = nitrate/nitrite tolerance, P opt = phosphate optimum, P tol = phosphate tolerance, S opt = salinity optima, S tol = salinity tolerance, Tu opt = turbidity optima, Tu tol = turbidity tolerance.

Name	Species code	N opt $\mu g\ N\ L^{-1}$	N tol $\mu g\ N\ L^{-1}$	P opt $\mu g\ P\ L^{-1}$	P tol $\mu g\ P\ L^{-1}$	S opt ppt	S tol ppt	Tu opt NTU	Tu tol NTU
Achnanthes angustata	OPE3	5.5	5.9	16.1	2.8	27.9	8.1	6.7	2.6
Amphora sp. 1	AMP3	40.6	16.4	58.0	4.9	32.0	3.8	11.1	2.6
Amphora sp. 2	AMP4	6.3	6.6	11.3	2.6	29.6	5.5	6.7	2.1
Amphora coffeaeformis	AMPcof	3.9	4.2	10.4	3.0	28.4	7.9	6.8	2.0
Amphora cf. *strigosa*	AMP9	6.3	5.9	16.6	3.7	29.1	6.9	5.2	2.1
Bacillaria paxillifer	NITscal	4.8	4.2	11.6	3.1	27.2	9.1	8.8	2.3
Biremis lucens	UNK7	5.6	6.7	9.2	2.8	26 6	7.9	6.9	1.9
Catenula adherens	AMP1	6.1	7.1	17.2	2.9	28.2	7.1	6.6	2.4
Cocconeis sp. 1	UNK107	10.8	5.1	13.6	3.4	31.8	4.1	9.0	2.4
Cocconeis scutellum	COCscu	4.8	4.3	18.2	4.2	29.3	7.2	7.7	1.5
Cocconeis scutellum var. 1	COCdis	7.0	6.3	35.9	4.8	31.6	5.7	7.7	1.6
Coscinodiscus centralis	CEN1	6.4	3.9	7.5	1.6	31.1	6.8	15.3	2.8
Cyclotella striata	CYCstr	2.9	3.9	6.5	1.7	24.0	7.3	6.6	1.5
Fallacia pseudony	FAL5	3 4	6.5	12.8	2.7	26.6	6.2	4.9	1.8
Fragilaria ellipta agg	CEN5	4 6	3 4	9.8	2.3	28.6	7.8	9.8	1.7
Grammatophora macilenta	GRA3	1.8	0.5	37.3	6.8	33.1	4.6	1.2	0.6
Grammatophora oceanica	GRAoce	2.1	2.0	9.0	2.8	27.6	6 4	5.9	1.3
Melosira nummuloides	MEL	12.8	1.6	3.9	0.7	30.5	8.5	13.4	4.4
Navicula sp. 1	UNK30	3.6	4.4	10.7	2.4	27.2	6.9	6.2	2.3
Navicula cf. *lusoria*	ACH14	15.8	9.9	66.5	2.3	33.9	2.0	4.0	3.1
Navicula perminuta	NAVper	4.4	3.8	13.8	2.5	27.8	7.7	7.3	1.5
Navicula recens	NAV7	4.3	5.5	20.7	3.2	29 6	6.8	8.0	2.7
Nitzschia valdestriata	NITval	3.9	6.0	23.0	3.4	29.3	6.7	5.5	2.4
Opephora guenter grassi	OPEgue	5.2	6.2	18.0	3.7	27.4	7.9	7.7	2.2
Opephora pacifica	OPEbur	6.2	7.5	19.6	2.3	26.6	7.8	7.7	2.8
Paralia sp. 1	PARsul	6.6	6.7	15.8	2.6	29.6	7.3	12.0	1.8
Planothidium hauckianium	PLAhau	6.0	6.2	23.3	3.1	28.4	7.1	6.1	1.9
Planothidium delicatulum	PLAdel	7.0	6.5	15.8	2.4	27.1	7.0	6.8	2.3
Pleurosigma cf. *salinarum*	GYRbal	9.6	8.7	22.3	4.3	30.7	6.7	11.0	2.0

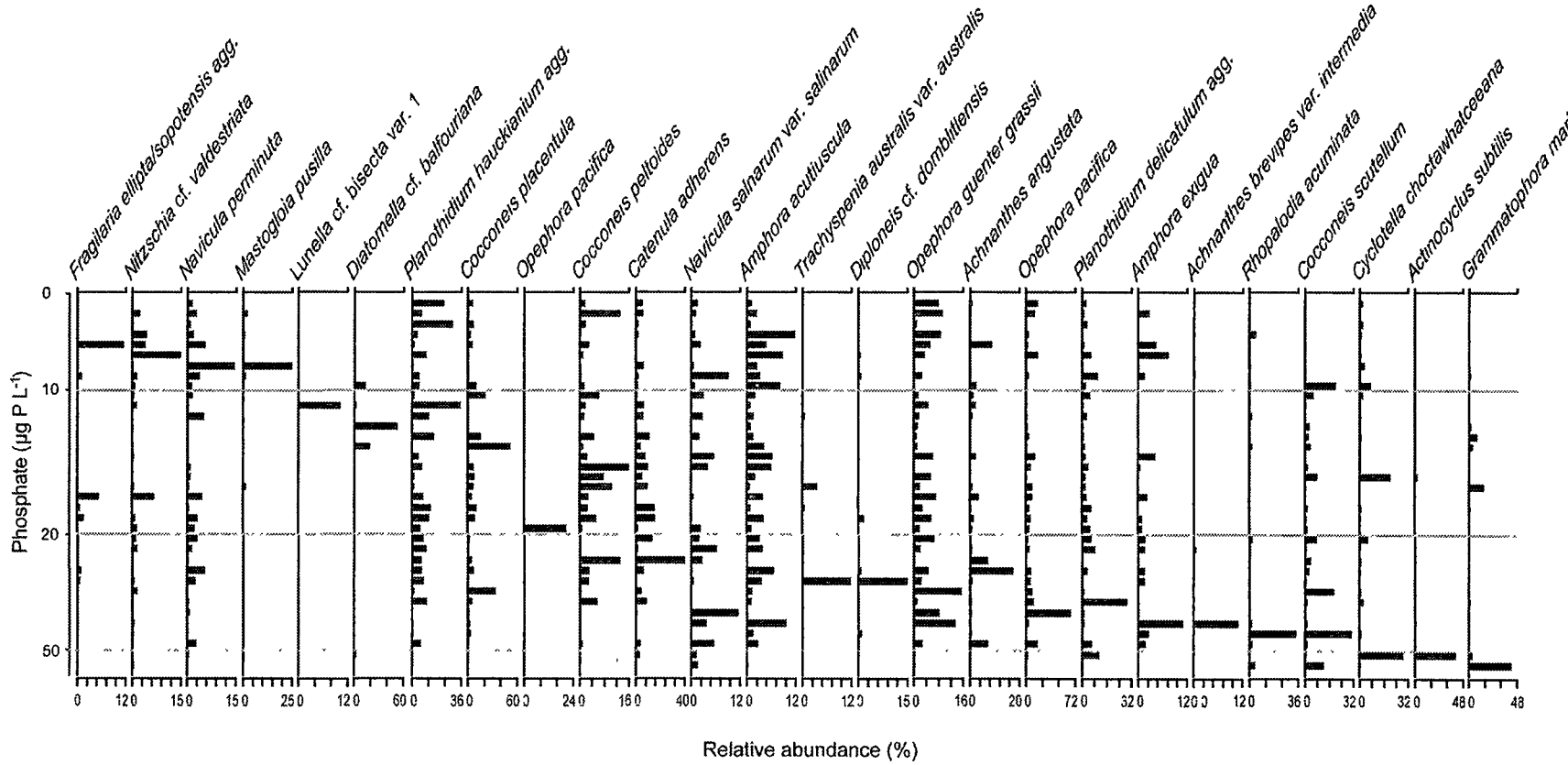


Figure 3.26: Dominant species distribution in the Tasmanian dataset ordered along the phosphate gradient

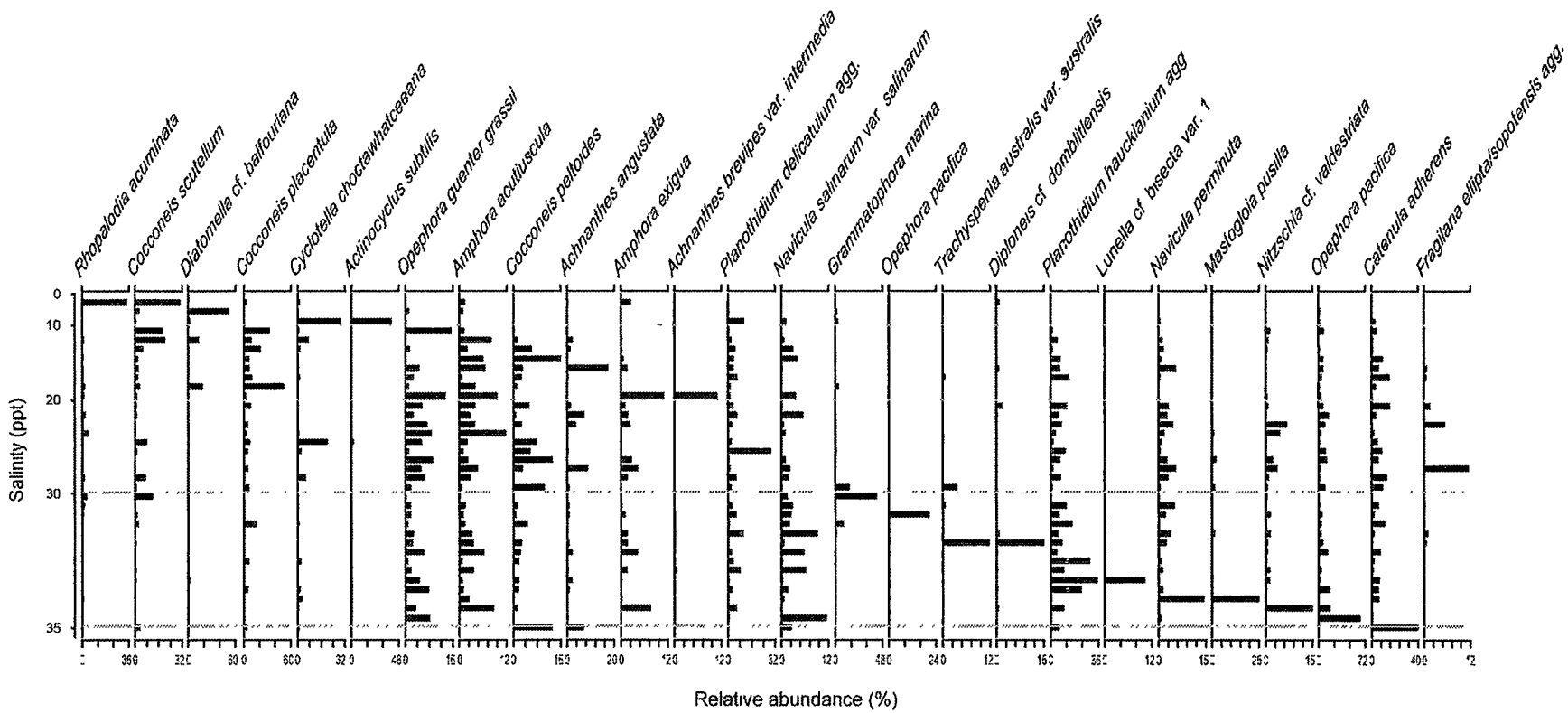


Figure 3.27: Dominant species distribution in the Tasmanian dataset ordered along the salinity gradient

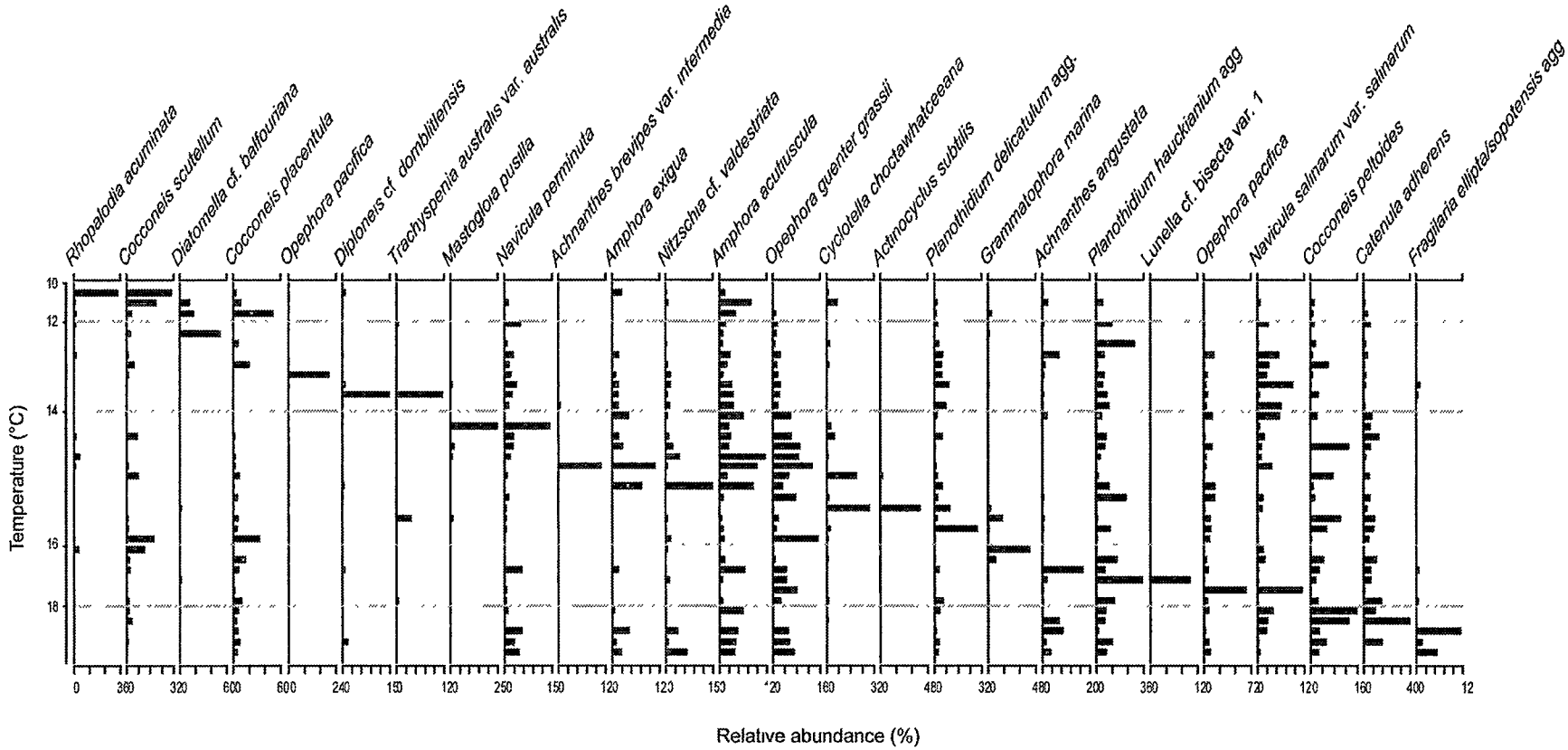


Figure 3.28: Dominant species distribution in the Tasmanian dataset ordered along the temperature gradient

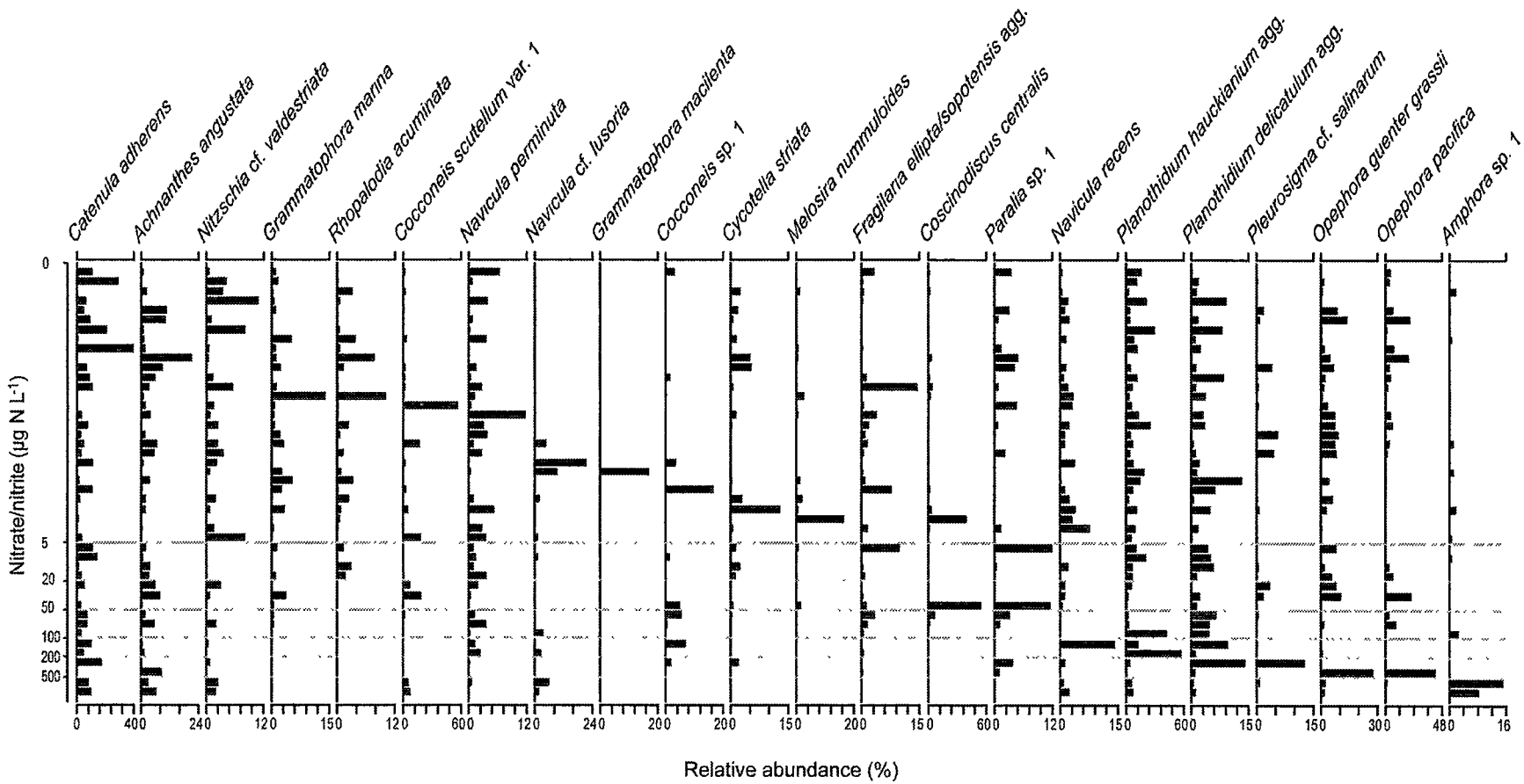


Figure 3.29: Dominant species distribution in the Victorian dataset ordered along the nitrate/nitrite gradient

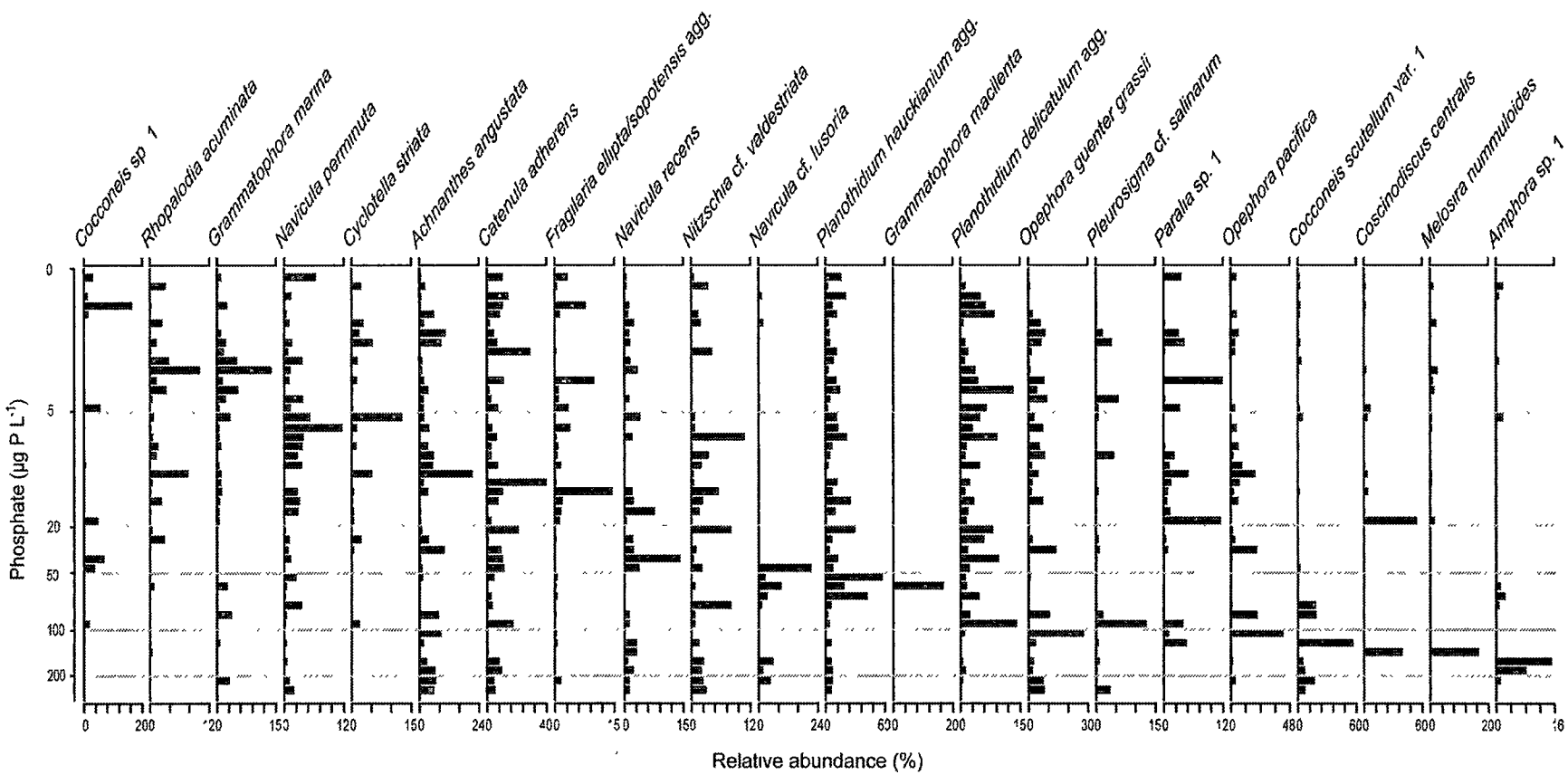


Figure 3.30: Dominant species distribution in the Victorian dataset ordered along the phosphate gradient

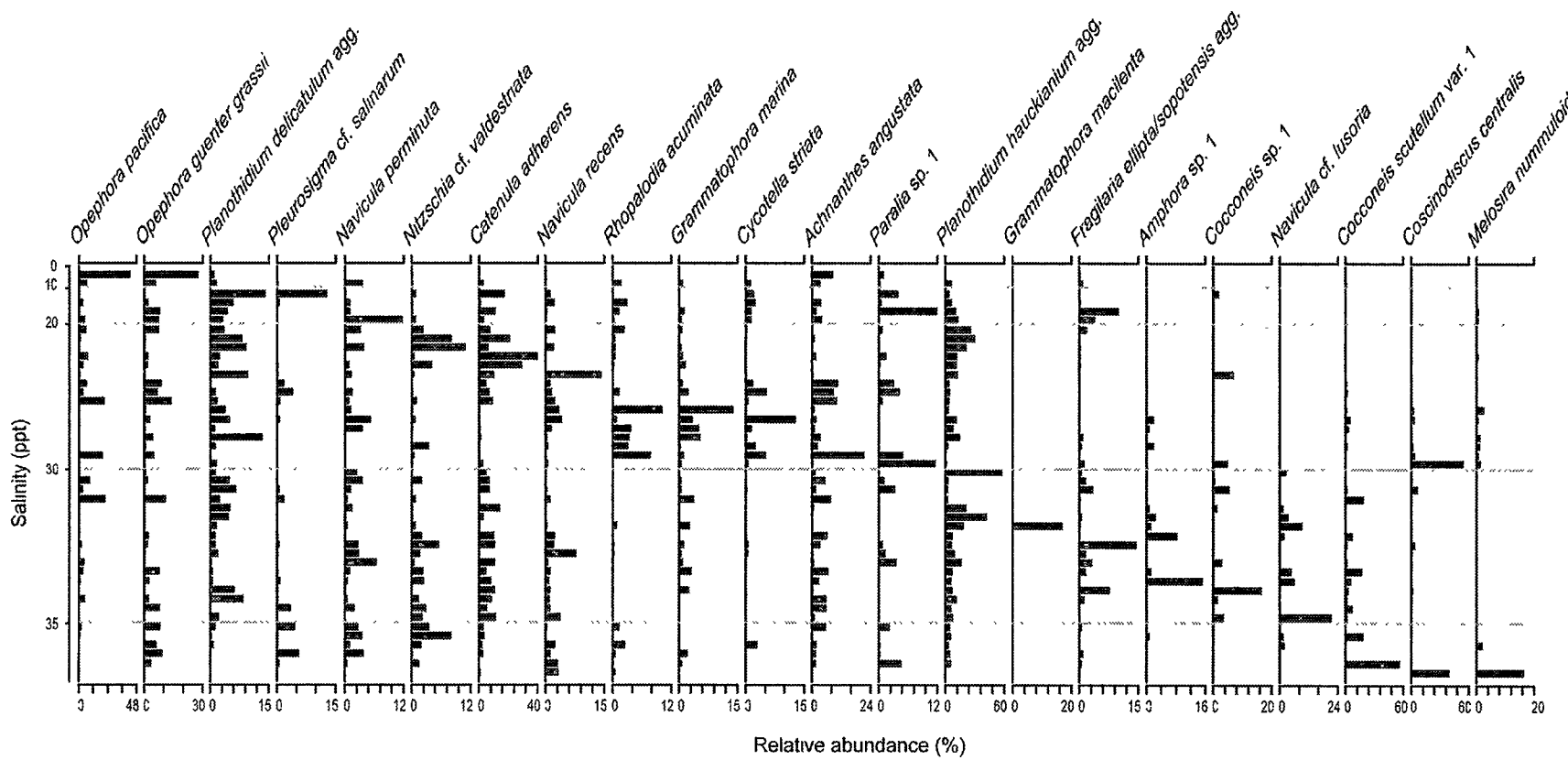


Figure 3.31: Dominant species distribution in the Victorian dataset ordered along the salinity gradient

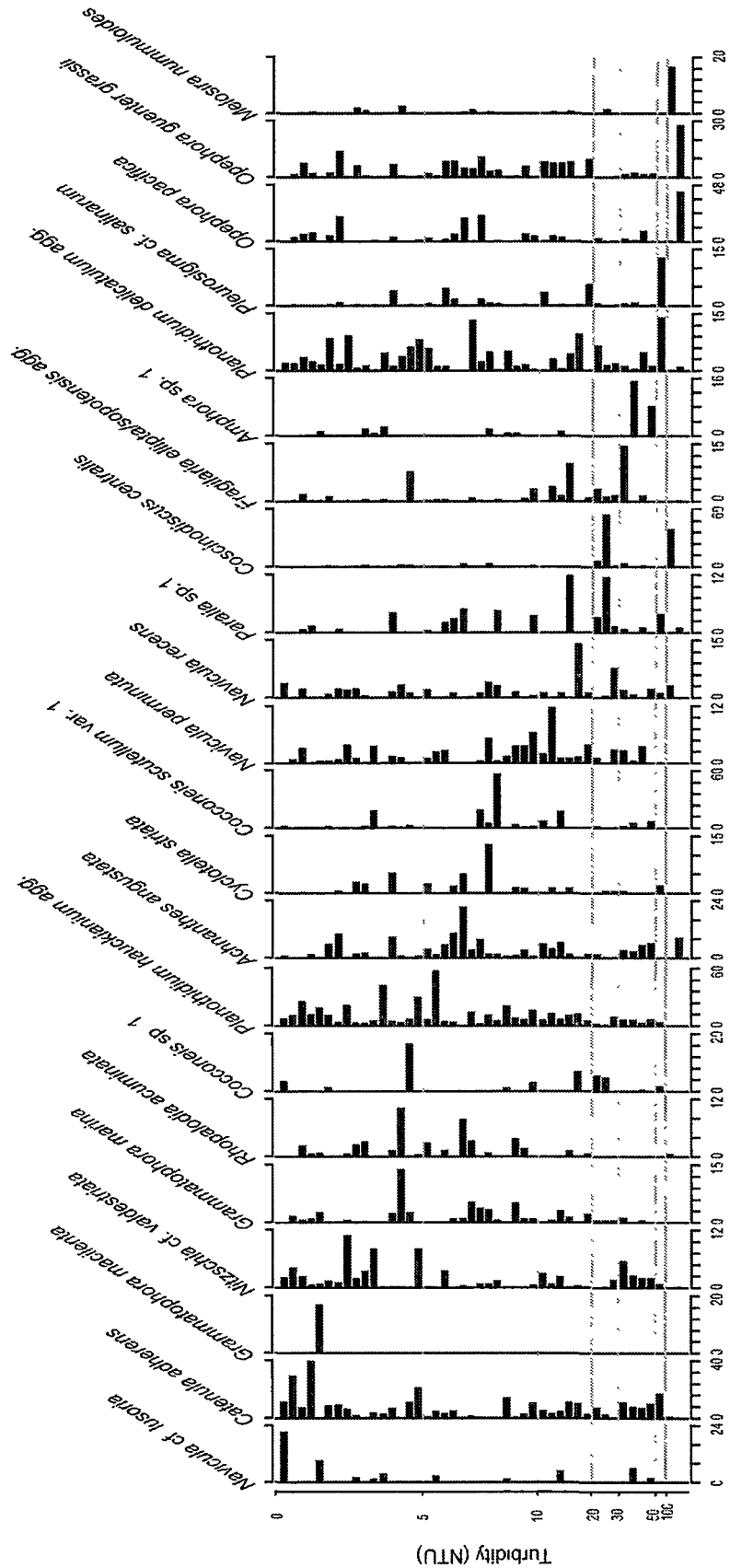


Figure 3.32: Dominant species distribution in the Victorian dataset ordered along the turbidity gradient

These Figures allowed the identification of species with preferences for high and low conditions of each environmental variable:

(a) Tasmanian species optima and tolerances

- *Fragilaria ellipta* agg., *Mastogloia pusilla* and *Nitzschia* cf. *valdestriata* were more abundant at sites with phosphate concentrations < 10 μg P L^{-1}, while *Actinocyclus subtilis*, *Cyclotella choctawhatceeana* and *Grammatophora marina* were more abundant at sites with phosphate concentrations > 50 μg P L^{-1} (Figure 3.26).
- *Cocconeis scutellum*, *Diatomella* cf. *balfouriana* and *Rhopalodia acuminata* were more abundant sites with salinity < 10 ppt, while *Catenula adherens*, *Mastogloia pusilla*, *Navicula perminuta*, *Nitzschia* cf. *valdestriata* and *Opephora pacifica* were more abundant at sites with salinity greater than ≥ 34 ppt (Figure 3.27).
- *Diatomella* cf. *balfouriana*, *Cocconeis placentula*, *Cocconeis scutellum* and *Rhopalodia acuminata* were more abundant at sites that were < 12 °C water temperature, while *Catenula adherens*, *Cocconeis peltoides* and *Fragilaria ellipta* agg. were more abundant at sites that were > 18 °C water temperature (Figure 3.28).

(b) Victorian diatom species optima and tolerances

- *Rhopalodia acuminata* did not occur at sites with nitrate/nitrite concentrations greater than 20 μg N L^{-1}, while *Amphora* sp. 1 and *Planothidium delicatulum* agg., *Pleurosigma* cf. *salinarum*, *Opephora guenter grassii* and *Opephora pacifica* were more abundant at sites with nitrate/nitrite concentrations > 200 μ g N L^{-1} (Figure 3.29).
- *Cocconeis* sp.1, *Rhopalodia acuminata* and *Grammatophora oceanica* were more abundant at phosphate sites with phosphate concentrations < 5 μg P L^{-1}, while *Amphora* sp. 1, *Melosira nummuloides*, *Cocconeis scutellum* var. 1, *Coscinodiscus centralis* and *Opephora pacifica* were

more abundant at sites with phosphate concentrations > 100 μg P L^{-1} (Figure 3.30).

- *Opephora pacifica* and *Opephora guenter grassii* were more abundant at brackish sites (i.e. < 10 ppt), while *Melosira nummuloides*, *Coscinodiscus centralis* and *Cocconeis scutellum* var. 1 were more abundant at hypersaline sites (i.e. > 35 ppt, Figure 3.31).
- Most diatoms were spread across the turbidity gradient, however *Catenula adherens*, *Grammatophora macilena* and *Navicula* cf. *lusoria* were more abundant at low turbidity sites (i.e. < 5 NTU), while *Opephora pacifica, Opephora guenter grassii* and *Melosira nummuloides* were more abundant at high turbidity sites (i.e. > 100 NTU, Figure 3.32).

3.3.5 Development of transfer functions

Based on the identification of the variables that explained independent portions of the variance in the diatom data in the Tasmanian and Victorian datasets, transfer functions for these environmental variables were developed. Due to the strong influence of latitude on diatom species, a diatom-latitude transfer function was developed for the combined Tasmanian and Victorian dataset. The relatively large amount of interaction between longitude and the other environmental variables, together with its comparatively small independent explanation of diatom species distribution, meant that developing a diatom-longitude transfer function was not appropriate. As location was an important factor for diatom distribution in the overall dataset, transfer functions for inferring water chemistry variables were developed for Tasmania and Victoria separately.

Transfer functions were developed using simple weighted averaging (WA) and weighted averaging partial least squares (WAPLS) to determine which model led to be best performing transfer functions. The output of WAPLS results in five components that can be used for transfer function development. To improve the predictive abilities of the transfer functions, visual outliers based on observed and inferred values were identified and removed. Sites were removed until transfer function performance did not improve with the removal of additional sites. Results are summarised in Table 3.16.

WAPLS-2 components resulted in the best performing latitude transfer function, but there was a clear separation between Tasmanian and Victorian sites (Figure 3.33). WAPLS-2 components also led to the best performing transfer function for the Tasmanian and Victorian phosphate transfer functions (Figures 3.34-3.35), Tasmanian temperature transfer function (Figure 3.36), Victorian nitrate/nitrite transfer function (Figure 3.37) and Victorian turbidity transfer function (Figure 3.38). Simple WA led to the best performing transfer functions for both Tasmanian and Victorian salinity transfer functions (Figures 3.39-3.40). However, while both salinity transfer functions had relatively good r^2 (i.e. 0.70 and 0.82 for Tasmania and Victoria respectively), they had relatively poor predictive performance and large errors (i.e. RMSE and RMSEp, Table 3.16).

The Victorian phosphate transfer function had the best predictive ability ($r^2p = 0.62$), while the Tasmanian phosphate transfer function had the worst predictive ability ($r^2p = 0.20$).

The Tasmanian temperature transfer function also had a good r^2 (i.e. $r^2 = 0.90$), but it had low predictive ability ($r^2p = 0.34$), as was the case for the Victorian turbidity transfer function (i.e. $r^2 = 0.91$, $r^2p = 0.23$, Table 3.16).

Table 3.16: Transfer function results for latitude (based on the combined Tasmanian and Victorian datasets) and the significant explanatory variables in the individual Tasmanian and Victorian datasets. All models are jackknifed, except the Tasmanian salinity transfer function, which is bootstrapped. Note: n = number of sites used in the final model, $r^2p = r^2$ of prediction, RMSE = root mean squared error, RMSEp = root mean squared error of prediction, N = nitrate/nitrite, P = phosphate, ppt = parts per thousand. See Appendix 1 for site names.

Variable	Model	r^2	r^2p	RMSE	RMSEp	n	sites removed
Latitude							
Combined	WAPLS-2	0.82	0.49	0.62	0.81°S	81	none
Nitrate/nitrite							
Victorian	WAPLS-2	0.91	0.44	0.24	0.63 log µg N L^{-1}	43	AI2, WPB4
Phosphate							
Tasmanian	WAPLS-2	0.94	0.17	0.07	0.27 log µg P L^{-1}	36	none
Victorian	WAPLS-2	0.94	0.62	0.15	0.39 log µg P L^{-1}	40	AI3, CI3, P14, WPB1, WPB4
Salinity							
Tasmanian	WA_{inv}	0.71	0.36	0.15	0.20 log ppt	36	none
Victorian	WA_{inv}	0.82	0.45	3.35	3.33 ppt	42	AI1, P4, LT4
Temperature							
Tasmanian	WAPLS-2	0.90	0.34	0.68	1.76 °C	36	none
Turbidity							
Victorian	WAPLS-2	0.91	0.23	0.15	0.45 log NTU	45	none

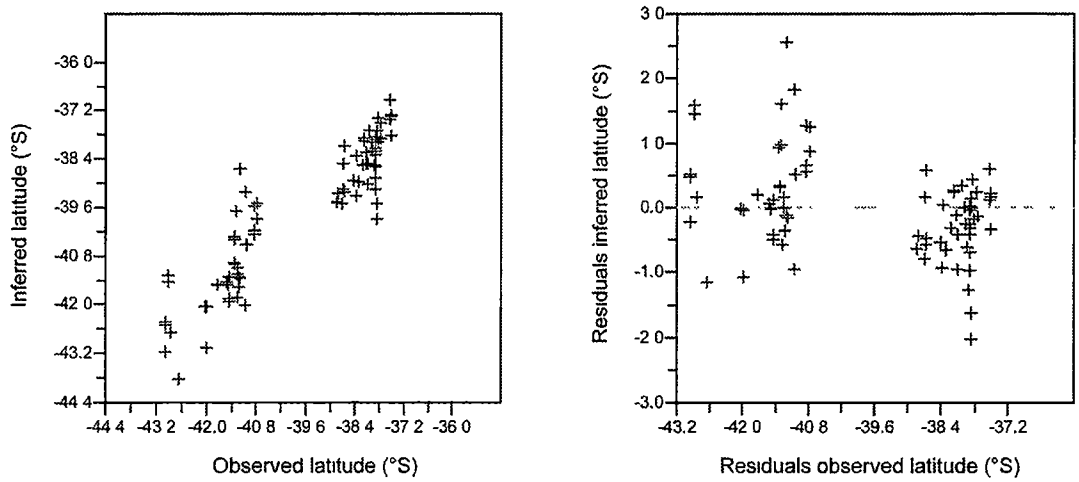


Figure 3.33: Latitude transfer function performance of the combined Tasmanian and Victorian datasets

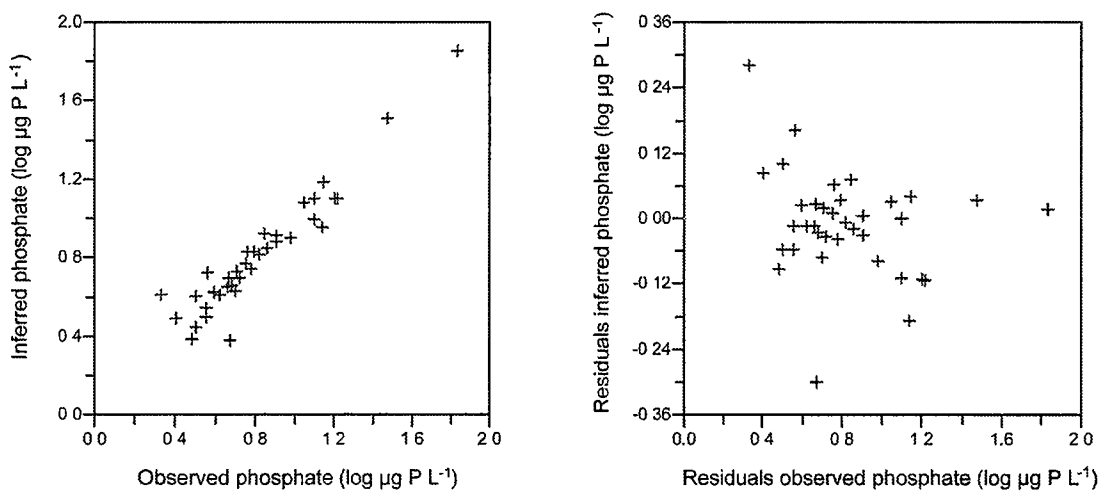


Figure 3.34: Phosphate transfer function performance of the Tasmanian dataset

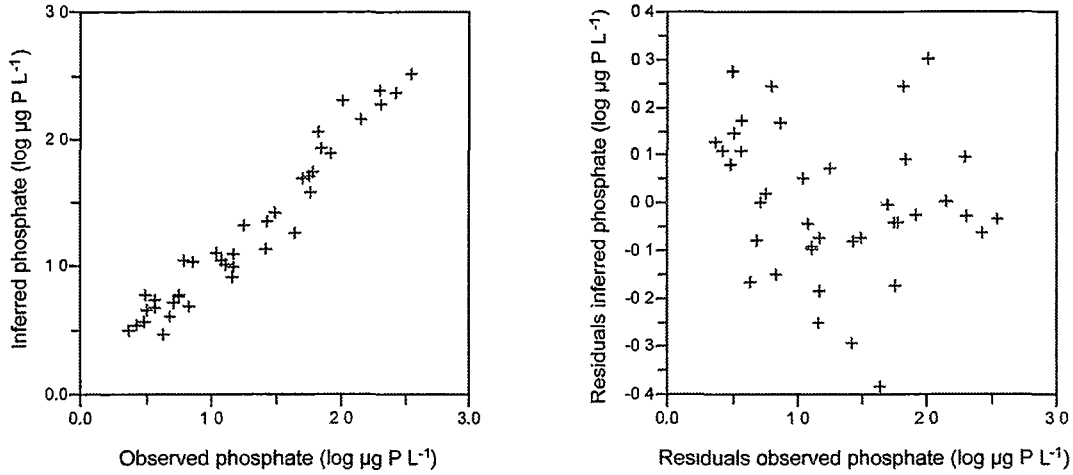


Figure 3.35: Phosphate transfer function performance of the Victorian dataset

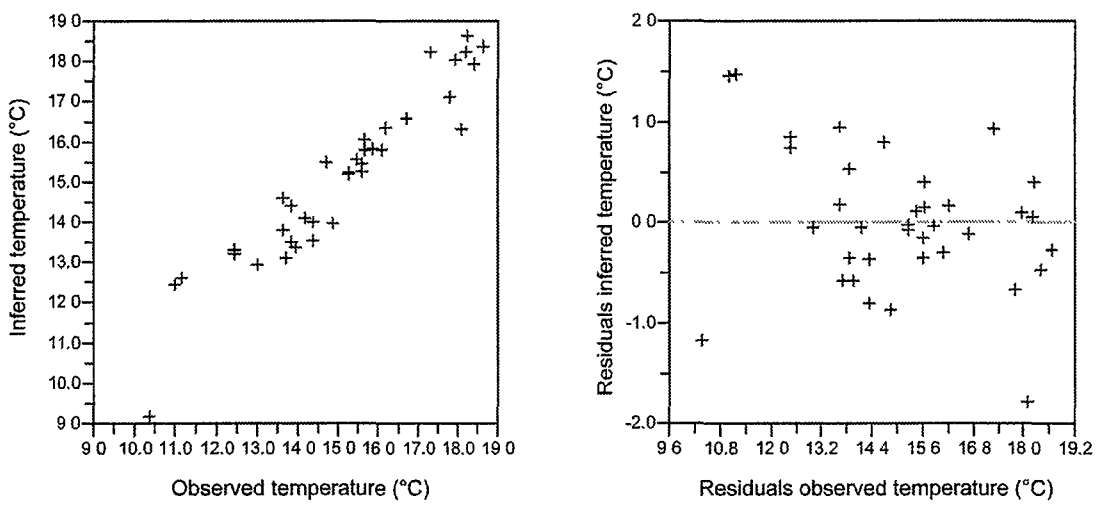


Figure 3.36: Temperature transfer function performance of the Tasmanian dataset

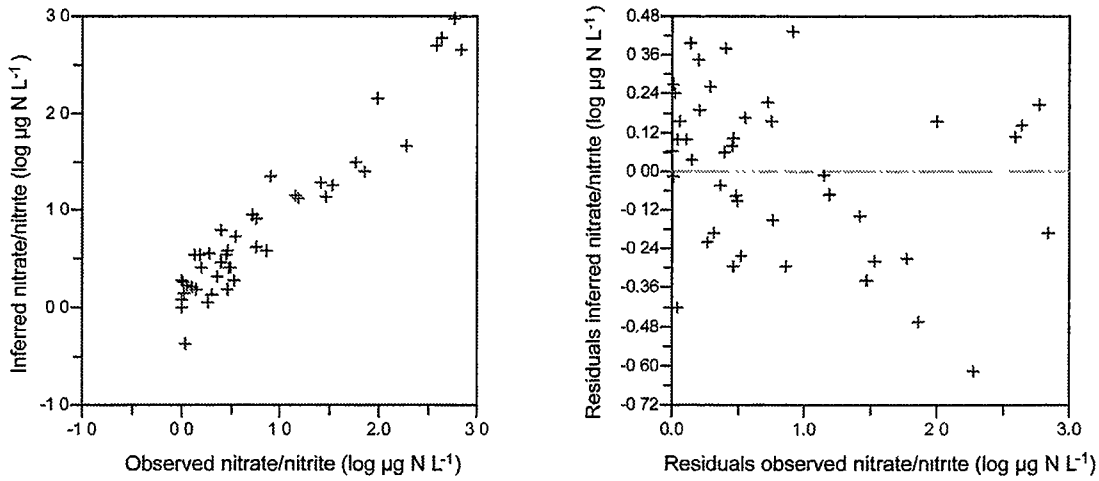


Figure 3.37: Nitrate/nitrite transfer function performance of the Victorian dataset

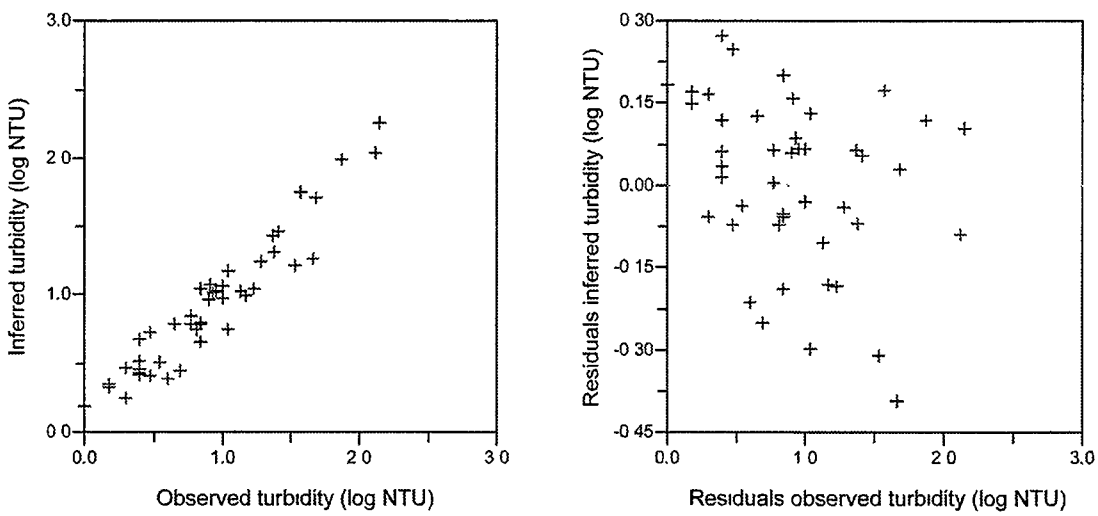


Figure 3.38: Turbidity transfer function performance of the Victorian dataset

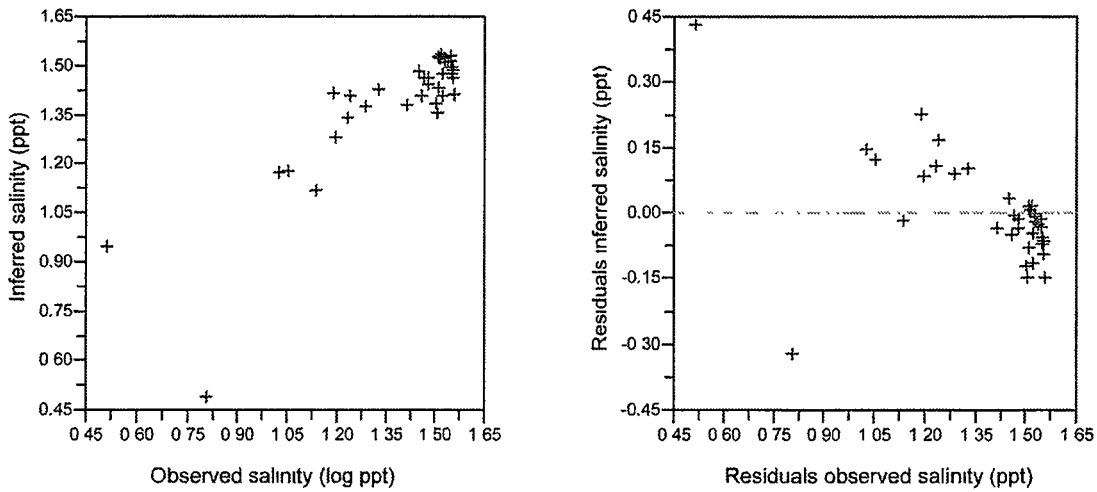


Figure 3.39: Salinity transfer function performance of the Tasmanian dataset

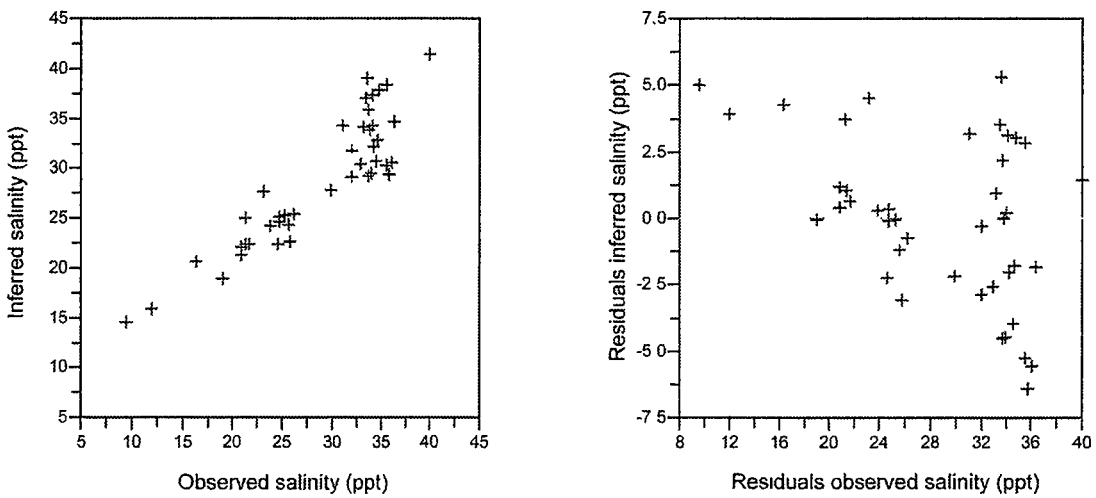


Figure 3.40: Salinity transfer function performance of the Victorian dataset

3.4 Discussion

The aims of this Chapter were to determine the similarities and differences in major environmental gradients occurring in Tasmanian and Victorian coastal water bodies and their influence on diatom species; to provide baseline, species-level data on the composition and distribution of surface sediment diatom communities of coastal water bodies in Tasmania and Victoria and their ecological preferences; and to develop transfer functions based on these environmental variables. The datasets were analysed separately and together to determine regional and overall similarities and differences.

3.4.1 Water quality parameters: similarities and differences

Water quality characteristics varied widely in the datasets, which reflected the complex patterns of nutrient, oxygen and salinity associated with different land use types, river inputs, influence from the sea and other local and regional influences (Weckström *et al.* 2002). Water quality differences between Tasmania and Victoria are primarily related to differences in nutrient and dissolved oxygen concentrations (Table 3.1). Mean nitrate/nitrite and phosphate was approximately eight times greater in Victorian sites compared with Tasmanian sites and no Tasmanian sites had nitrate/nitrite concentrations ≥ 55 μg N L^{-1} or phosphate ≥ 70 μg P L^{-1}, while the greatest nitrate/nitrite concentration recorded in Victorian sites was 696 μg N L^{-1} and the greatest phosphate concentration was 348 μg P L^{-1}. However, the low median for nitrate/nitrite concentration and, to a lesser extent phosphate concentration, in Victorian sites indicates that high nutrient sites were in the minority (Table 3.1). This was also found by Philibert *et al.* (2006) in their study of southeast mainland Australian streams, where the majority of sites had low nutrient values. Mean and median dissolved oxygen in Victorian sites was almost half that of Tasmanian sites (i.e. mean 4.99 mg L^{-1} compared to mean 9.28 mg L^{-1} and median 4.50 mg L^{-1} compared to mean 9.58 mg L^{-1} in Victoria and Tasmania respectively, Table 3.1), despite the maximum dissolved oxygen recorded in Victorian sites being greater than in Tasmanian sites (i.e. 18.9 mg L^{-1}

compared to 13.0 mg L^{-1}). This indicates that in general, Tasmanian sites have lower nutrient concentrations and higher dissolved oxygen than Victorian sites.

3.4.2 Diatom distribution: similarities and differences

The total number of species identified (i.e. 247 in Tasmania, 342 in Victoria and 399 in total) highlighted the wide diversity of diatom taxa in the southeast Australian coastal region. While the Tasmanian and Victorian datasets shared many of the same species, an additional 157 species occurred in the Victorian dataset that did not occur in the Tasmanian dataset, while 56 species were limited to the Tasmanian dataset (see Appendix 2 for species occurrences). The most common and widespread taxa in both regions are considered to be cosmopolitan species, characteristic of brackish, coastal and marine water bodies (Witkowski *et al.* 2000) and have been identified in previous Australian coastal diatom studies (e.g. Fluin *et al.* 2007, Haynes *et al.* 2007, Saunders *et al.* 2007, Taffs *et al.* 2008).

The lack of endemic species in the Tasmanian dataset provided a contrast to previous Tasmanian diatom studies conducted in inland alpine, west and southwest Tasmania, which have found endemic taxa in freshwater lakes (e.g. Vyverman *et al.* 1995, Tyler 1996, Hodgson *et al.* 1997). There are marked differences in geology, climate, vegetation and land use history between west and east Tasmania, which is strongly reflected in the distribution of terrestrial and aquatic biota (Vyverman *et al.* 1995, Hodgson *et al.* 1997). In comparison to west and southwest Tasmania, east Tasmania is more climatically and geologically similar to southeast mainland Australia (BOM 2007). Diatom assemblages identified in recent unpublished studies of southwest Tasmanian coastal lakes and lagoons indicate very different diatom assemblages to the dataset presented in this study (K. Saunders, *unpublished*), with more similarity to species identified by Vyverman *et al.* (1995), Hodgson *et al.* (1997) and some Macquarie Island sites (see Chapter 5).

3.4.3 Species ecological preferences

Little is known about diatom species ecological preferences in southeast Australian coastal lakes, lagoons and estuaries. This study therefore contributes new information on the ecological preferences of coastal diatoms in Tasmania and Victoria.

Species characteristic of low nutrient (i.e. phosphate) environments in Tasmania include *Fragilaria ellipta* agg., *Nitzschia* cf. *valdestriata* and *Mastogloia pusilla*. Species characteristic of low nutrient environments (i.e. phosphate and nitrate/nitrite) in Victoria include *Cocconeis* sp. 1, *Rhopalodia acuminata*, *Grammatophora oceanica* (Figures 3.26, 3.28, 3.30)

Species characteristic of high nutrient environments in Tasmania include *Rhopalodia acuminata*, *Actinocyclus subtilis* and *Achnanthes brevipes* var. *intermedia*. Species characteristic of high nutrient environments in Victoria include *Amphora* sp. 1, *Melosira nummuloides*, *Coscinodiscus centralis* and *Opephora pacifica* (Figures 3.27, 3.29, 3.30). The identification of *Rhopalodia acuminata* as a species with a preference for relatively high nutrient concentrations in Tasmania but relatively low nutrient preference in Victoria may be a reflection of the smaller nutrient range and relatively large proportion of sites with low nutrient values in Tasmania, which influences the derived species optima and tolerances.

Species characteristic of low salinity conditions in Tasmania include *Rhopalodia acuminata*, *Cocconeis scutellum*, *Diatomella* cf. *balfouriana*, *Actinocyclus subtilis*. Species characteristic of low salinity conditions in Victoria include *Opephora pacifica*, *Opephora guenter grassii*, *Planothidium delicatulum* agg. and *Pleurosigma salinarum* (Figures 3.27, 3.31)

Species characteristic of marine conditions in Tasmania include *Navicula perminuta*, *Mastogloia pusilla*, *Nitzschia* cf. *valdestriata*, *Opephora pacifica* and *Catenula adherens*. Species characteristic of marine conditions in Victoria include *Melosira nummuloides*, *Coscinodiscus centralis* and *Cocconeis scutellum* var. 1 (Figures 3.29, 3.31).

Phosphate and salinity were identified as explaining independent portions of the variance in the diatom data in both the Tasmanian and Victorian datasets. Therefore the environmental optima of diatom species were compared to

investigate regional similarities and differences in ecological preferences for these variables. Comparisons of the salinity optima of species identified in both datasets indicated that Tasmanian diatom species salinity optima were, in general, similar to the optima derived for the same species in the Victorian dataset (Figure 3.41).

Comparisons of the phosphate optima of species identified in both datasets indicated that Tasmanian diatom phosphate optima were consistently lower than Victorian diatom phosphate optima (Figure 3.42). Despite this, species with higher phosphate optima in the Tasmanian dataset generally had higher phosphate optima in the Victorian dataset set, while species with lower phosphate optima in the Tasmanian dataset also had lower phosphate optima in the Victorian dataset. It is possible that the phosphate optima derived for the diatoms in the Tasmanian dataset are under-estimated, which is a consequence of the shorter gradient sampled in the Tasmanian dataset in comparison to the Victorian dataset in this study (i.e. maximum phosphate measured in the Tasmanian dataset was 64.5 μg P L^{-1} compared to 347.6 μg P L^{-1} in the Victorian dataset, Table 3.1). Further sampling to increase the phosphate range of the Tasmanian dataset could result in more reliable and realistic predictions of diatom phosphate optima and the identification of high phosphate indicator species for Tasmanian coastal water bodies.

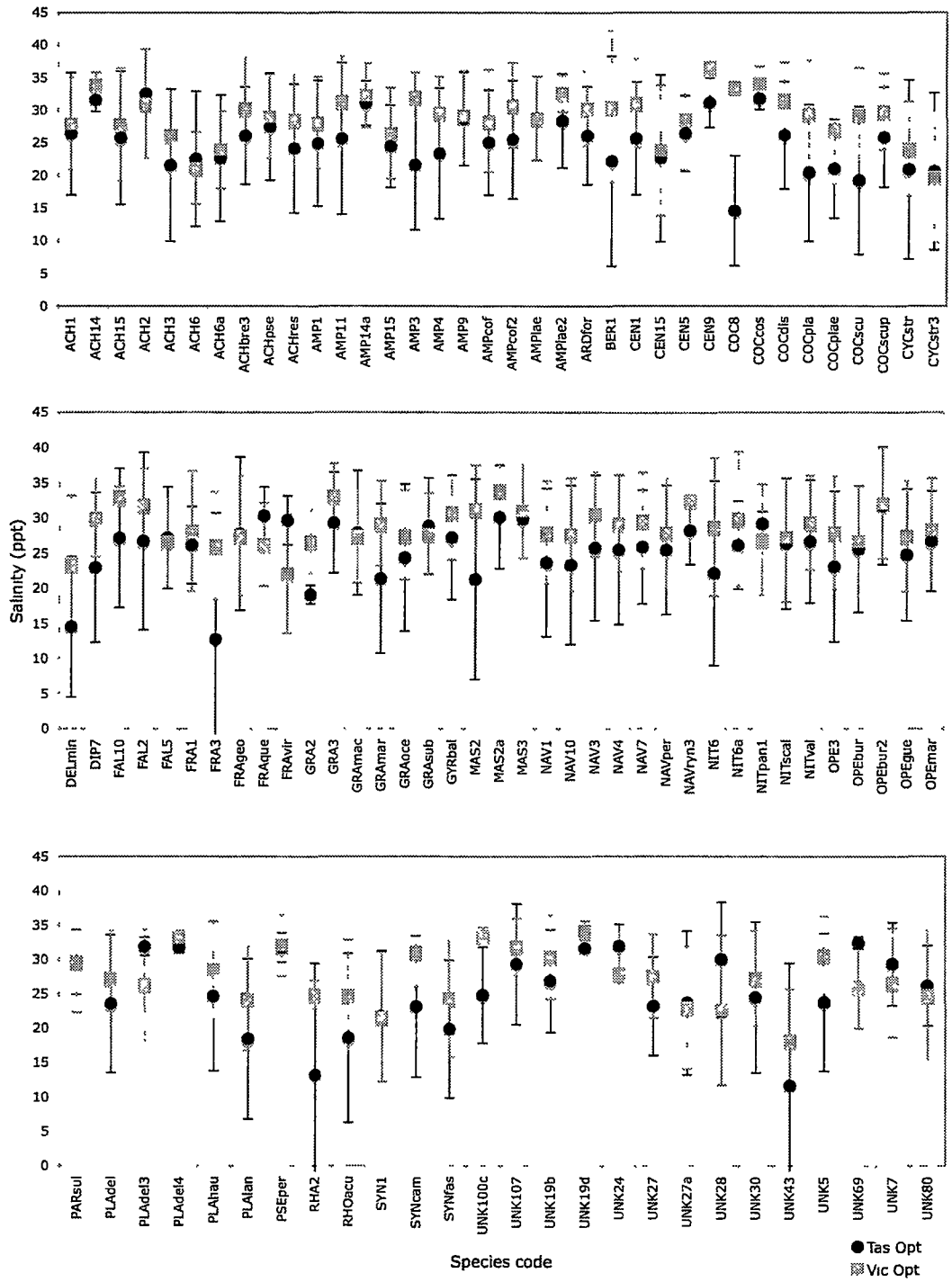


Figure 3.41: Comparison of species salinity optima for the same species in the Tasmanian and Victorian datasets. Calculated tolerances are indicated by error bars. Note: Tas Opt = Tasmanian species optimum, Vic Opt = Victorian species optimum. See Appendix 2 for species names.

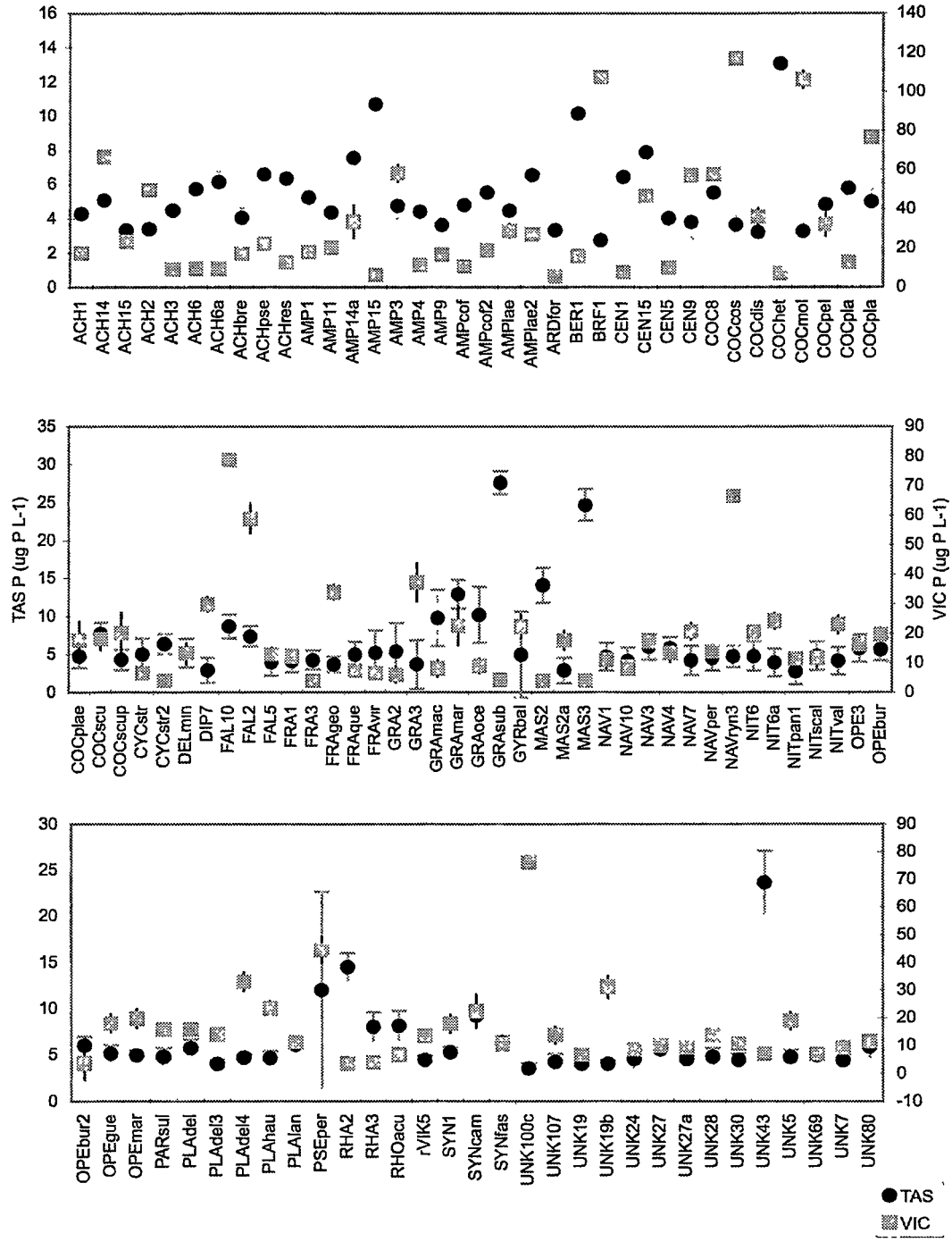


Figure 3.42: Comparison of species phosphate optima for the same species in the Tasmanian and Victorian datasets. Calculated tolerances are indicated by error bars. Note: Tas Opt = Tasmanian species optimum, Vic Opt = Victorian species optimum. See Appendix 2 for species names.

3.4.4 Evaluation of transfer functions

The independent influence of latitude and to a lesser extent longitude, indicates the strong influence of location on southeast Australian coastal diatom assemblages. Similarly, Johnson *et al.* (2007) demonstrated the importance of latitude, longitude and regional variability in explaining among-site differences in community structure in a range of organisms from diatoms to fish, Philibert *et al.* (2006) found geospatial variability was a key determinant in diatom species distribution of southeast mainland Australian streams and Reavie *et al.* (2006) identified the important influence of latitude and longitude on diatom assemblage characteristics of the Great Lakes, USA. As a result of the influence of location, Philibert *et al.* (2006) recommended that developing transfer functions for smaller sub-regions may remove some of the influence of geographical variables, which may otherwise obscure some of the variance caused by the measured water quality variables. Consequently, transfer functions for the two datasets were developed separately.

The best performing transfer functions for nutrients and salinity were developed using WAPLS-2 and simple WA models respectively. This has been found to be the most appropriate in previous coastal palaeoecological studies (e.g. Clarke *et al.* 2003, Martin 2001, Weckström *et al.* 2004, Table 3.17).

The Victorian phosphate transfer function had the best predictive ability and had comparable performance to previously published diatom phosphorus-based transfer functions (see Table 3.17). Despite a good r^2, low RMSE and RMSEp, the Tasmanian phosphate transfer function had poor predictive ability (i.e. $r^2p = 0.20$). This is likely to be due to the lack of a long, evenly spaced nutrient gradient. The Tasmanian temperature transfer function also had relatively weak predictive ability, despite a good r^2 (i.e. $r^2 = 0.90$, $r^2p = 0.34$ and RMSEp = 1.67 °C). Use of diatom-temperature transfer functions are appropriate for extreme environments such as high latitude and high altitude regions, where long temperature gradients occur (e.g. Joynt & Wolfe 2001, Gremmen *et al.* 2007), but may not be appropriate to use in Tasmanian coastal water bodies as it may be difficult to differentiate between a genuine temperature change compared to an apparent diatom-temperature change driven by response to another variable.

Table 3.17: Previously published transfer function performances. References in bold are coastal studies. Note: n = number of sites, NOx = nitrate/nitrite, TDN = total dissolved nitrogen, TN = total nitrogen, PO4 = phosphate, TP = total phosporus, r^2p = predicted r^2, RMSE = root mean squared error, RMSEp = root mean squared error of prediction, WA = weighted averaging, WAcla = weighted averaging with classical deshrinking, WAinv = weighted averagıng with inverse deshrinking, WAPLS-2 = weighted averaging partial least squares 2 components.

Authors	Variable	Model	r^2	r^2p	RMSE	RMSEp	n
Nitrogen-based							
This study (Victorian)	**NOx**	**WAPLS-2**	**0.91**	**0.44**	**0.24**	**0.63 log µg N L^{-1}**	**43**
Weckström *et al.* (2004)	**TDN**	**WAPLS-2**	**0.89**	**0.73**	**0.05**	**0.09 log_{10} units**	**45**
Werner & Smol (2005)	TN	WAPLS-2	0.69	0.42		0.11 log µg TN L^{-1}	
Phosphorus-based							
This study (Tasmanian)	**PO_4**	**WAPLS-2**	**0.94**	**0.17**	**0.07**	**0.27 log µg P L^{-1}**	**36**
This study (Victorian)	**PO_4**	**WAPLS-2**	**0.94**	**0.62**	**0.15**	**0.39 log µg P L^{-1}**	**40**
Bennion *et al.* (1996)	TP	WAPLS-2	0.91	-	0.15	0.21 log µg L^{-1}	152
Bradshaw & Anderson (2001)	TP	WA	0.75	0.47	0.17	0.24 µg TP L^{-1}	45
Hall & Smol (1992)	TP	WA	0.86	0.73	0.25 µg L^{-1}		37
Martin (2001)	TP	WAPLS-2	-	0.59	-	0.33 log µg TP L^{-1}	36
Reavie *et al.* (2006)	TP	WA	0.75	0.65	0.22	0.26 log µg L^{-1}	
Tibby (2004)	TP	WAPLS-2	0.94	0.74	0.11	0.23 log µg TP L^{-1}	33
Werner & Smol (2005)	TP	WA_{cla}	0.57	0.44	-	0.20 log µg TP L^{-1}	
Salinity							
This study (Tasmanian)		**WA_{inv}**	**0.71**	**0.36**	**0.15**	**0.20 log ppt**	**36**
This study (Victorian)		**WA_{inv}**	**0.82**	**0.45**	**3.35**	**3.33 ppt**	**42**
Clarke *et al.* (2003)		**WAPLS**	**0.84**	**-**	**-**	**0.15 log TN**	**70**
Davies *et al.* (2002)		WA	0.91	-	0.25	0.42 (µS cm^{-1})	53
Martin (2001)		WA_{inv}	0.85	0.58	-	0.78 log g L^{-1} sal	36
Ryves *et al.* (2004)		**WAPLS-2**	**0.977**	**0.887**	**0.11**	**0.246 log g L^{-1} sal**	**36**
Wilson *et al.* (1996)		WA	0.87	-	-	0.37 log ppt	219
Temperature							
This study (Tasmanian)		**WAPLS-2**	0.90	0.34	0.68	1.76 °C	36
Bigler *et al.* (2000)		WAPLS-2	0.86	0.51	0.11	1.87°C	42
Joynt & Wolfe (2001)		WA	0.48	1.94	2.79°C		
Rosen *et al.* (2000)		WAPLS-3	0.92	0.62	0.40	0.86°C	52

The salinity transfer functions for both Tasmanian and Victorian datasets, while having good predictive ability (as defined by Philibert *et al.* 2006, where transfer functions with $r^2 > 0.6$ and $r^2p > 0.36$ had good predictive ability), did not perform as well as previously published salinity transfer functions (Table 3.17). This is surprising as salinity has previously been found to be the overriding environmental variable influencing Australian diatom communities, with several diatom-salinity (or conductivity) relationships previously being established (e.g. Hodgson *et al.* 1997, Blinn & Bailey 2001, Gell *et al.* 2002, Philibert *et al.* 2006, Saunders *et al.* 2007, Tibby *et al.* 2007). However, with the exception of Hodgson *et al.* 1997 and Saunders *et al.* (2007), these studies were not conducted in coastal lakes or estuaries. This suggests that while salinity explains the most variation in the diatom data for this study, other environmental variables such as nutrients (in particular phosphate) also play important roles in Australian coastal water bodies.

Saunders *et al.* (2007) developed a salinity transfer function using many of the same sites in the Tasmanian dataset also used in this study. The difference in transfer function performances may be a result of only making two seasonal water chemistry measurements, which may not be enough to characterise the variability experienced at the sites. Due to a 12 month gap between the samples collection by Saunders *et al.* (2007) and this study, and the absence of nutrient data in Saunders *et al.* (2007), the datasets were not combined. It is possible that salinity varies on an inter-annual basis and is likely to be influenced by rainfall patterns prior to sampling. Southeast Australian rainfall is highly influenced by the Southern Oscillation Index (SOI), which can result in El Niño and La Niña events in southeast Australia. These events influence the amount of rainfall in the region and consequently the salinity experienced in coastal water bodies, occurring at irregular intervals of approximately 5-7 years and usually lasting 1 to 2 years (BOM 2007). Changes in rainfall from year to year would result in different salinities recorded at sites on a broad geographical scale and would have influenced the individual salinity measurements used in the reference dataset. Tibby *et al.* (2007) found that sites that were variable over a 5-6 year period in wetlands in northwest Victoria had greater transfer function model error than sites with large seasonal differences, but smaller inter-annual differences. It is possible that the salinity of Tasmanian sites also vary on an inter-annual basis, which has the potential to cause different transfer function performance statistics.

This has implications for reference dataset development. Future development of these transfer functions needs to take the annual and inter-annual variability of water quality parameters into account and ensure that sampling occurs more regularly throughout the year and over multiple years to span both El Niño and La Niña events. This would ensure that temporal variability is more accurately captured. An understanding of seasonal and annual variability in water quality variables and the time frame spanned by surface sediment diatom assemblages is needed in order to determine an appropriate frequency and duration for the collection of the environmental data to develop reference datasets. This is particularly important for developing diatom datasets such as these into management tools.

3.4.5 Implications and recommendations for future development of the datasets

This study has highlighted some of the differences between Tasmanian and southeast mainland Australian coastal water chemistry and environmental gradients. This has important implications for Australian National Water Quality Guidelines. While Australia-wide policies are needed to control environmental degradation of coastal water bodies, it is important that attempts are made based on locally-derived data in order to set appropriate baselines and targets. The National Water Quality Guidelines set the same guidelines and targets for both Tasmania and Victoria, as they are part of the 'southeast region' that also includes New South Wales, the Australian Capital Territory and southern Queensland (NLWRA 2000). These guidelines have been established with no data from Tasmania (NLWRA 2000). The water quality data measured in this study indicates lower nutrient conditions in Tasmania compared to Victoria (i.e. maximum nitrate/nitrite was 52.5 $\mu g\ N\ L^{-1}$ compared to 696.1 $\mu g\ N\ L^{-1}$, while maximum phosphate was 67.5 $\mu g\ P\ L^{-1}$ compared to 347.6 $\mu g\ P\ L^{-1}$ in Tasmania and Victoria respectively, Table 3.1). Additionally, virtually all taxa in the Tasmanian dataset had phosphate optima considerably less than those derived from the Victorian dataset for the same species (Figure 3.46).

The differences in the datasets between derived salinity and phosphate optima for the same species highlights the importance of developing diatom-based datasets and transfer functions from the region they are going to be applied to (Battarbee *et al.* 2001). To apply the Tasmanian dataset to a Victorian site is likely to result in underestimation of diatom-inferred phosphate concentrations, while applying the Victorian dataset to a Tasmanian site may result in an overestimation of diatom-inferred phosphate concentrations. Thus, applying the same water quality guidelines and 'trigger values' for Tasmania and Victoria is problematic. Trigger values are values determined as part of the Australian National Water Quality Guidelines where outside of this figure there is a possible risk to water quality. This requires, under the guidelines, action to either further investigate or fix the cause of the problem (NLWRA 2000).

While this study contributes new data on southeast Australian diatom species ecological preferences and resulted in the development of a series of transfer functions, there are some factors that need to be considered when interpreting the results and applications. The Tasmanian and Victorian datasets are based on a limited number of measurements to determine environmental gradients. This is a common practice, but also widely acknowledged as a problem in the dataset development process (Battarbee *et al.* 2001). To ensure the environmental data capture the temporal variability experienced at the sites, a more extensive sampling strategy is needed. Bennion and Smith (2000) recommend at least four measurements over a 12 month period. This was not possible in the present study due to time restraints, but is recommended in future work.

To account for spatial variability in some of the larger Victorian and Tasmanian coastal water bodies, multiple near-shore samples from each were collected. For example, Port Phillip Bay in Victoria (Figure 3.1) was sampled at 14 locations. Sites were chosen in relation to different distances from potential sources of variability in measured environmental variables (e.g. distance from nutrient sources and the entrance to the ocean). This means that there is a degree of autocorrelation present in the dataset, which can 'artificially' improve the performance of transfer functions (Telford & Birks 2005). However, sampling multiple locations within these water bodies was required in order to incorporate some of the inherent spatial variability characteristic of large coastal lagoon and

estuarine systems, particularly with respect to the point source inputs of rivers, marine inputs and pollution sources. One way to address the issue of autocorrelation would be to integrate samples collected from each water body into a single sample before developing the transfer functions. However, this would obscure some of the natural spatial variability that occurs within these water bodies.

The non-selection of nitrate/nitrite in the Tasmanian dataset as an independent, explanatory variable and the weak performance of the Tasmanian phosphate transfer function is probably due to the limited phosphate gradient and lower overall nutrient concentrations measured in Tasmania compared with Victoria (Table 3.1). The addition of more mid to high nutrient sites in the Tasmanian dataset may permit the development of transfer functions with better predictive ability and may allow the development of a nitrate/nitrite transfer function. Similarly, the addition of more high salinity (i.e. ≥ 35 ppt) sites may help to improve the predictive abilities of the salinity transfer functions.

In addition to the variables measured in this study, it would be useful to include measurements of total phosphorus and total nitrogen. These are considered to be less variable than phosphate and nitrate/nitrite (Bennion & Smith 2000) and many water quality guidelines use total phosphorus and total nitrogen in preference (e.g. the Australian National Water Quality Guidelines use total phosphorus in preference to phosphate, NLWRA 2000).

3.5 Conclusions

This study has provided a general overview of water quality in Tasmanian and Victorian coastal lakes, lagoons and estuaries, the composition of diatom assemblages and major environmental variables determining species distribution.

Latitude and to a lesser extent, longitude, influenced diatom species occurrence, which highlights the geographic variability of diatom taxa in southeast Australian coastal water bodies. Phosphate, salinity and temperature explained independent portions of the variance in Tasmanian coastal diatom assemblages. The salinity transfer function performed relatively well, but had poorer predictive ability than previously published salinity transfer functions. The temperature and phosphate transfer functions had weak predictive ability.

Nitrate/nitrite, phosphate, salinity and turbidity explained independent portions of the variance in Victorian coastal diatom assemblages and well performing transfer functions for phosphate and to a lesser extent, salinity, were developed. The next Chapter describes the application of the Victorian salinity and phosphate transfer functions to a sediment core.

Application of the Victorian transfer functions to determine water quality changes since European settlement in Lake King, Gippsland Lakes

The work presented in this Chapter has been published as:
Saunders KM, Hodgson DA, Harrison J, McMinn A (2008) Palaeoecological tools for improving the management of coastal ecosystems: a case study from Lake King (Gippsland Lakes) Australia. *Journal of Paleolimnology* **40**: 33-47.

4.1 Introduction

Lake King is one of three interconnected lakes known as the Gippsland Lakes in the southeast corner of mainland Australia (Figure 4.1). It is the largest estuarine lagoon system in Australia, covers 340 km^2 and has a catchment area greater than 20,000 km^2.

The region is a former marine embayment that became separated from the sea by the deposition of successive sand barriers during the Pleistocene and Holocene (Bird 1993). This created a large fresh-brackish lake system with an entrance only open to the sea during periods of high river flows (Bird 1965).

The Gippsland Lakes are listed under the Ramsar Convention as wetlands of international importance. The lakes are also listed as part of the Japan-Australia Migratory Birds Agreement and China-Australia Migratory Birds Agreement (Malcolm 2002). The Gippsland Lakes provide important feeding, resting and breeding habitats for approximately 80 waterbird species and support an estimated 4% of Victoria's shorebird population. The permanence of the lakes and the regular flooding of the adjacent wetlands provide an important drought refuge for many waterbirds (Parks Victoria 2003).

Land use practices since the arrival of Europeans in the 1840s have resulted in extensive clearance of lowland areas and nearby forests, mercury discharge into the lakes as a consequence of gold mining, draining of wetlands and diversion of water for agriculture, industry, forestry and urban use (Winstanley 1995). These practices have led to increased delivery of nutrients and sediments to the lakes and altered the freshwater flow regime of the rivers in the catchment. These, in turn, have had substantial influences on the ecosystem health of the Gippsland Lakes.

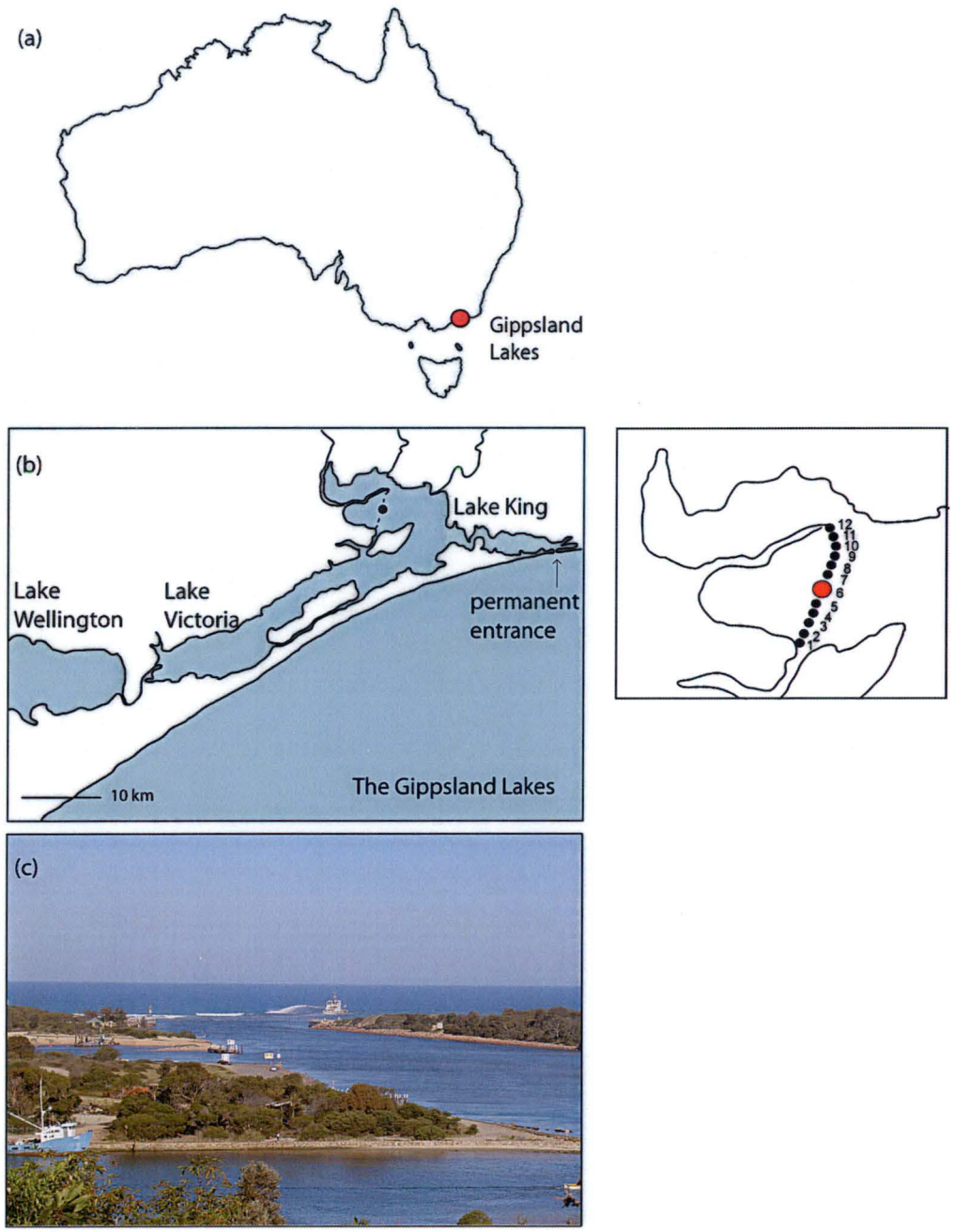


Figure 4.1: (a) Location of the Gippland Lakes on the Australian mainland; (b) location of Lake King and the permanent entrance. The location of the core and one transect site (red dot) and remaining transect sites (black dots) are numbered and expanded to the side; and (c) Lakes Entrance (the permanent entrance to the ocean).

Major environmental issues include declining water quality, high nutrient concentrations (from direct and diffuse sources), algal blooms, declining freshwater macrophyte communities (particularly freshwater marshes), shoreline erosion, reduced suitable habitat for waterbirds, stratification and anoxic bottom

waters, and introduced exotic plants and animals (Webster *et al.* 2001, Winstanley 1995). An artificial channel between Lake King and the sea was constructed in 1889 to aid transport in the area (Figure 4.1). Subsequently, the salinity of the lakes increased and they regularly experience stratification (Bird 1993, Winstanley 1995). The Gippsland Lakes, as they are today, are a relatively recent phenomenon.

Improving the water quality of the Gippsland Lakes has become an important issue. Of all the Gippsland Lakes, Lake King has been the most directly affected by the permanent entrance. It receives major nutrient inputs from three large rivers and experiences the most prolonged periods of stratification and algal blooms. As yet no palaeolimnological study of Lake King has been undertaken to reconstruct environmental changes since European settlement in order to investigate nutrient changes and anthropogenic impacts on this part of the Gippsland Lakes.

4.2 Aims

The overall Aim of this Chapter is to contribute data that will assist the development of future management strategies to conserve the water quality of Lake King.

Specific Aims are to:

1. Investigate spatial variability of water chemistry and surface sediment diatom assemblages within Lake King (by conducting a transect) and incorporating the samples into the Victorian dataset described in Chapter 3.
2. Apply the transfer functions developed in Chapter 3 in order to establish baseline conditions, determine the impact of human activities including the construction of the permanent entrance to the sea, and to describe the nature and direction of environmental change since European settlement;
3. Use additional proxies (i.e. analyses of total sediment carbon, nitrogen and sulphur, chlorophyll *a* and particle size) to provide further evidence of changes in the lake's nutrient status, and organic and inorganic inputs to aid interpretation;

4. Apply a palaeolimnological approach to quantitatively reconstruct environmental changes and assess the ecological impacts of human activities in and around the lake.

4.3 Results

A transect was conducted across Lake King to investigate the spatial variability in environmental variables and diatom species within the lake. These results were incorporated into the Victorian phosphate and salinity transfer functions described in Chapter 3. A 120 cm sediment core was collected from a water depth of 7 m and analysed for diatoms, particle size, total sedimentary carbon, nitrogen, sulphur and chlorophyll *a* (Figure 4.1).

4.3.1 Summary of transect results

To tailor the transfer functions to Lake King, a 12 site transect was conducted across the lake at the same time as core collection, at varying depths to try and capture some of the spatial variability within the lake, particularly of nutrient concentrations associated with marine, riverine and point source inputs from the catchment. Sites were sampled at 500 m intervals across Lake King at depths ranging from 3.8-7.2 m. At each site, surface water chemistry was measured and surface sediment samples were collected (Figure 4.1, Table 4.1). Phosphate concentrations were low, but increased with depth (maximum 9.60 μg P L^{-1} at 7.0 m depth), as did silicate (maximum 1052 μg Si L^{-1} at 7.2 m depth) and dissolved oxygen (maximum 17.78 mg L^{-1} at 6.3 m depth). Nitrate/nitrite was not detected at most sites except for the northern most sites where it reached a maximum concentration of 66.7 μg N L^{-1}. Salinity increased from south to north until site 9, where it then steadily decreased to a minimum of 11.6 ppt at site 12. Temperature ranged from 7.0-9.2 °C, while pH was relatively steady and ranged from 7.49-7.68. Turbidity was low at all sites (1-4 NTU).

Table 4.1: Gippsland Lakes transect results. Note: Depth is in metres, N = nitrate/nitrite, P = phosphate, Si = silicate, Sal = salinity, Temp = temperature, Turb = turbidity, DO = dissolved oxygen, Secchi = secchi depth, NA = data not available.

Site	Depth	N	P	Si	Sal	Temp	pH	Turb	DO	Secchi
	m	μg N L^{-1}	μg P L^{-1}	μg Si L^{-1}	ppt	°C		NTU	mg L^{-1}	m
1	3.8	0.00	0.00	209	20.2	7.0	7.65	2	10.91	3.4
2	4.6	0.00	0.00	307	19.3	7.3	7.62	4	10.56	2.6
3	5.2	0.00	0.00	262	19.5	7.4	7.62	4	10.77	2.5
4	4.4	0.00	0.10	215	20.3	8.1	7.65	2	11.19	2.95
5	5.0	0.00	0.02	208	21.2	8.4	7.67	1	12.45	3.4
6	4.8	0.00	0.00	204	21.2	8.4	7.68	1	13.97	3.6
7	6.1	0.00	0.19	145	21.7	8.6	7.67	2	14.96	2.8
8	6.3	0.00	0.00	138	22.1	9.2	7.68	1	17.78	3.6
9	6.8	52.6	8.26	444	19	9.1	7.67	2	NA	3.7
10	7.0	45.5	9.60	651	15.8	8.8	7.61	2	NA	3.9
11	7.2	66.7	8.45	1052	10.7	8.2	7.52	3	NA	3.9
12	7.0	8.6	0.00	858	11.6	7.3	7.49	3	NA	3.9

4.3.2 Core chronology

The ^{210}Pb profile indicated little mixing of the sediment and the CIC model inferred a sedimentation rate of 0.74 cm yr^{-1} (0.28 ± 0.03 g cm^{-2} y^{-1}) to 60 cm (Figure 4.2). Below 60 cm ^{210}Pb activities were both low in activity and constant to the base of the core. The data points below 60 cm were not used in the sedimentation rate calculations. However, major changes in the diatom assemblages and sedimentary carbon, nitrogen and sulphur contents occurred at 80 cm, which was interpreted as marking the construction of the permanent entrance. Extrapolating a sedimentation rate of 0.74 cm yr^{-1} to 80 cm also indicates that 80 cm corresponds to c. 1890. The last 40 cm, while not possible to date with accuracy, provide a good record of the pre-permanent entrance (i.e. pre 1889) state of Lake King.

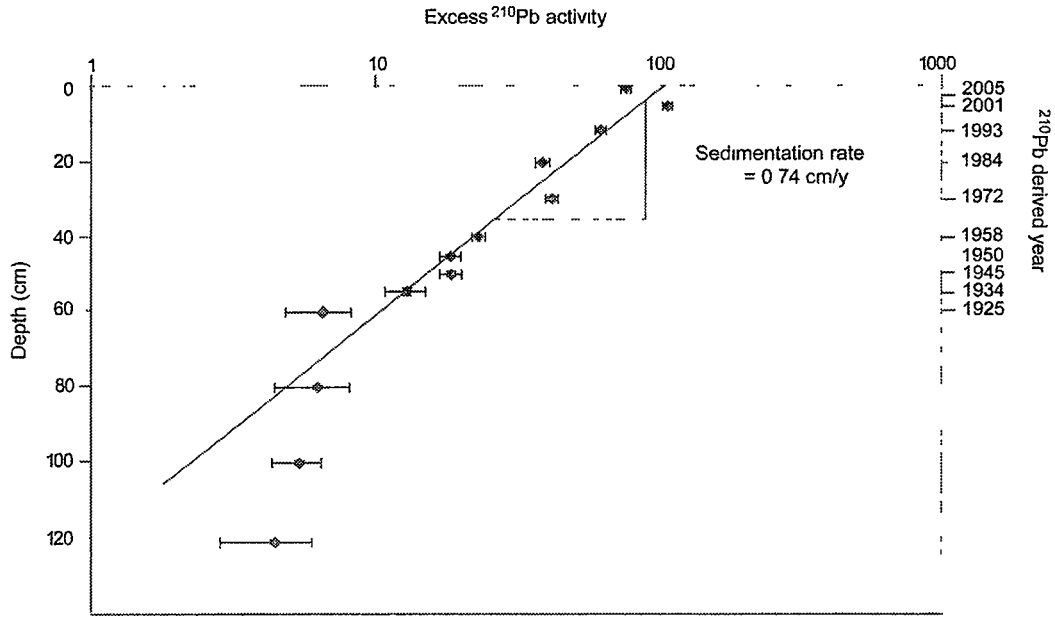


Figure 4.2: Unsupported ^{210}Pb activity in Lake King sediment core, indicating a sedimentation rate of 0.74 cm y^{-1}. Below 60 cm, activities were too low to use for dating purposes with accuracy.

4.3.3 Core stratigraphy

The core consisted of dark grey-black, fine-grained sediment with occasional plant macrofossils. Sediment composition was principally (~ 80%) mud (2-63 μm, Figure 4.3). Prior to the permanent entrance being constructed, the percentage of clay (< 2 μm) and mud was relatively stable, while two main peaks (up to 10.0%) in sand (> 63 μm) occurred. Coinciding with the construction of the permanent entrance there was a peak in clay (to 25.0%) followed by sand (to 12.0%). From c. 1920, the proportion of sand remained relatively stable until a peak of 12.0% at the top of the core, while the proportion of mud increased from c. 1915 onwards and clay particles decreased (Figure 4.3).

Total sulphur varied from 2.6-3.0% prior to the construction of the permanent entrance and was higher during this time than any period since. Both total carbon and total nitrogen were higher prior to construction of the permanent entrance. Two main peaks of total nitrogen were recorded c. 1920 and 1960 and total carbon and nitrogen increased from c. 1990-2005. The total carbon to total nitrogen (C:N) mole ratio of the sediment indicated that organic matter in the lake was principally derived from terrestrial rather than marine sources. There was a

large peak in the C:N mole ratio during the early 1900s, rising to 47.9, indicating large amounts of terrestrial inputs at this time (Figure 4.3).

4.3.4 Diatoms

A total of 201 diatom taxa were identified in the sediment core. Of these, 122 occurred with a relative abundance of ≥ 1% in ≥ 2 samples. There were 17 common taxa, occurring with a relative abundance ≥ 5% in ≥ 2 samples, and two of these (*Cyclotella choctawhatceeana* and *Cyclotella striata*) occurred in 58% of samples with ≥ 5% relative abundance (Figure 4.4, Table 4.2).

Below 80 cm, the core was dominated by peaks (in relative abundance) of planktonic *Cyclotella choctawhatceeana* (c. 70%) and *Cyclotella striata* (c. 12%), together with benthic diatoms *Cocconeis scutellum* var. *scutellum* (max. 10%), *Navicula viridula* (max. 18%), and *Surirella* sp. 1 (max. 8%) between 110-120 cm and *Fragilaria* cf. *subsalina* (max. 12%) from 100 cm (Figure 4.4).

Between the construction of the permanent entrance in 1889 and the 1920s, the relative abundance of *Bacillaria paxillifer*, *Nitzschia compressa* and *Pleurosigma salinarium* increased. From the 1920s to the mid 20th century there were increases in the relative abundance of benthic *Grammatophora oceanica* and *Catenula adherens* and planktonic *Chaetoceros* spp. (Figure 4.4).

During the mid 20th century, *Grammatophora macilenta* increased in relative abundance to > 8%, dominating the most recent sediments. Additionally, the upper part of the core was characterised by a virtual absence of *Fragilaria* cf. *subsalina, Nitzschia compressa* and *Coscinodiscus centralis*. *Skeletonema costatum* had a broad peak in the 1970s, before disappearing in the most recent sediments. There was a large increase in the relative abundance of *Diploneis* cf. *notabilis* in the early 1990s.

Both *Chaetoceros* spp. and *Skeletonema costatum* are lightly silicified taxa that breakdown easily and dissolve under oxic conditions; they are therefore often not well preserved in coastal sediments (MOLTEN 2004). Changes between oxic and anoxic conditions in the sediment may affect their representation in fossil assemblages.

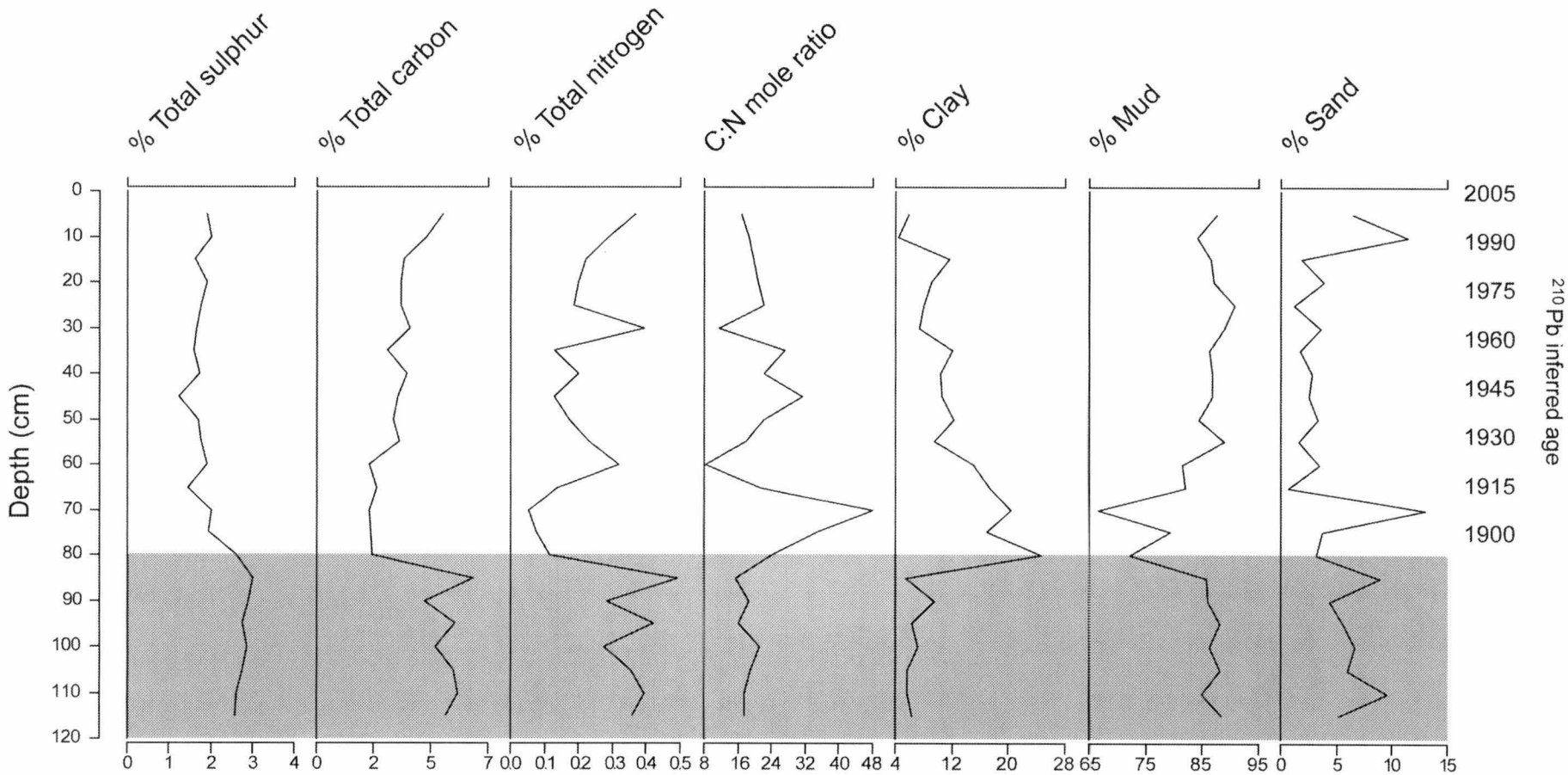


Figure 4.3: Total sediment sulphur (S), carbon (C) and nitrogen (N) contents, C:N mole ratio and particle size (clay < 2 μm, mud 2-63 μm, sand > 63 μm) in the Lake King sediment core. Pre-permanent entrance period indicated by grey shading.

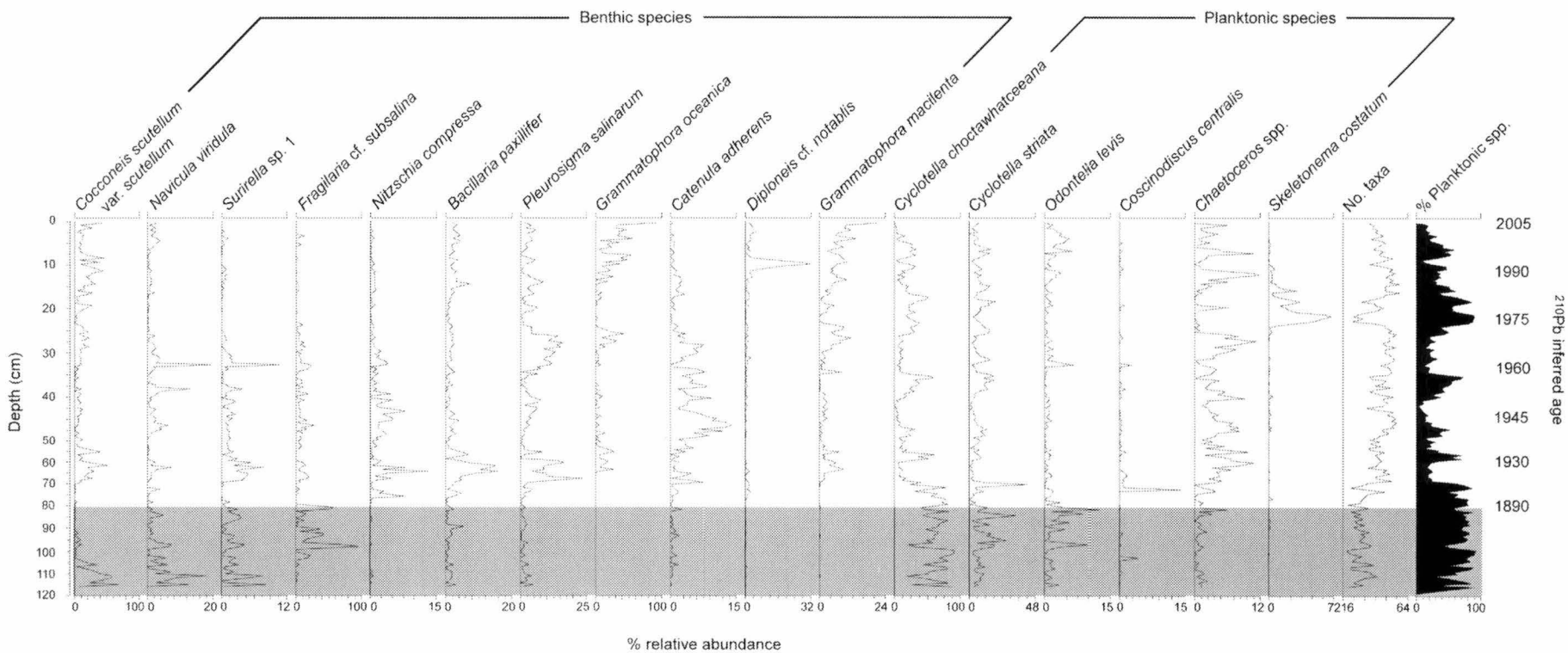


Figure 4.4: Stratigraphy of the common diatom taxa (i.e. species occurring with ≥ 5% relative abundance and in ≥ 2 samples) in the Lake King sediment core (all species are presented as % relative abundance). The number of taxa per core sample (No. taxa) and % planktonic taxa are also displayed. Pre-permanent entrance period indicated by grey shading.

Table 4.2: Common diatom taxa in the Lake King sediment core. Note: n_{core} = number of occurrences as % total number of core samples, Max_{core} = maximum relative abundance in core samples, n_{ref} = number of occurrences as % total number of reference dataset samples, Max_{ref} = maximum relative abundance in reference dataset samples, P opt = phosphate optimum, P tol = phosphate tolerance, S opt = salinity optimum, S tol = salinity tolerance.

Species	n_{core} %	Max_{core} %	n_{ref} %	Max_{ref} %	P opt µg P L^{-1}	P tol µg P L^{-1}	S opt ppt	S tol ppt
Benthic species								
Bacillaria paxillifer	94.0	16.2	58.0	5.16	11.6	3.13	25.4	8.54
Catenula adherens	82.9	13.8	81.1	39.6	17.8	3.19	26.8	7.69
Cocconeis scutellum	84.1	11.0	79.1	5.50	18.2	4.15	27.2	8.58
Diploneis cf. *notabilis*	63.5	31.6	not in calibration dataset					
Fragillaria cf. *subsalina*	58.8	11.6	5.71	2.79	20.7	4.61	31.6	6.35
Grammatophora macilenta	91.2	21.5	2.80	3.78	8.04	3.18	27.5	6.32
Grammatophora oceanica	43.5	9.05	67.9	15.4	8.95	2.80	27.4	6.43
Navicula viridula	84.7	19.6	15.1	1.98	1.18	2.40	20.8	5.63
Nitzschia compressa	68.8	13.3	15.1	1.27	6.48	1.73	20.9	7.18
Pleurosigma salinarium	92.9	23.3	95.3	12.6	16.1	3.05	28.6	5.76
Surirella sp. 1	71.8	10.76	4.20	3.02	8.33	0.01	15.5	5.87
Planktonic species								
Chaetocerous spp.	89.0	12.3	not in calibration dataset					
Cyclotella choctawhatceaena	99.4	87.3	37.7	12.8	6.51	1.70	23.4	7.46
Cyclotella striata	99.4	42.3	28.3	7.30	14.2	1.36	19.23	10.1
Odontella levis	78.2	12.6	not in calibration dataset					
Skeletonema costatum	35.3	69.2	not in calibration dataset					

The number of taxa found in each segment of the core was highest during the early-mid 20th century and declined from the 1980s to 2005. The number of taxa was closely linked to the proportion of planktonic taxa, as these species commonly dominated the Lake King diatom assemblage. The proportion of planktonic species was closely tied to the proportion of *Cyclotella choctawhatceeana* throughout the core and is a major factor driving the percent relative abundance of all planktonic diatoms. While the proportion of this taxon remained important in more recent sediments, *Chaetoceros* spp and *Skeletonema costatum* were responsible for the peaks in planktonic taxa during the 20th century.

In the 1980s a period of low numbers of taxa was due to the dominance of *Skeletonema costatum* (Figure 4.4).

4.3.5 Phosphate and salinity reconstructions

The species and environment data from the transect across Lake King were integrated into the Victorian dataset and transfer functions described in Chapter 3. The Victorian phosphate and salinity transfer functions were applied to the Lake King sediment core.

Reconstructed phosphate indicated that substantial nutrient changes have occurred since the late 19th century (Figure 4.5). Phosphate concentrations have doubled (i.e. from < 5 μg P L^{-1} to > 10 μg P L^{-1}) by the late 1880s. During the 20th century peaks in phosphate concentration occurred in the late 1930s, c. 1945 and late 1950s up to a maximum of 15 μg P L^{-1} before declining to below 10 μg P L^{-1} from c. 1970 to 2005.

While the salinity transfer function performed relatively poorly and cannot be used to provide a quantitative reconstruction, it does show a trend that agrees well with a qualitative assessment of changes in salinity from changes in the diatom assemblages (i.e. brackish vs. marine species). Together these indicate lower salinity prior to the permanent entrance, higher salinity for most of the 20th century and an overall decrease since the 1980s to 2005 (Figure 4.5).

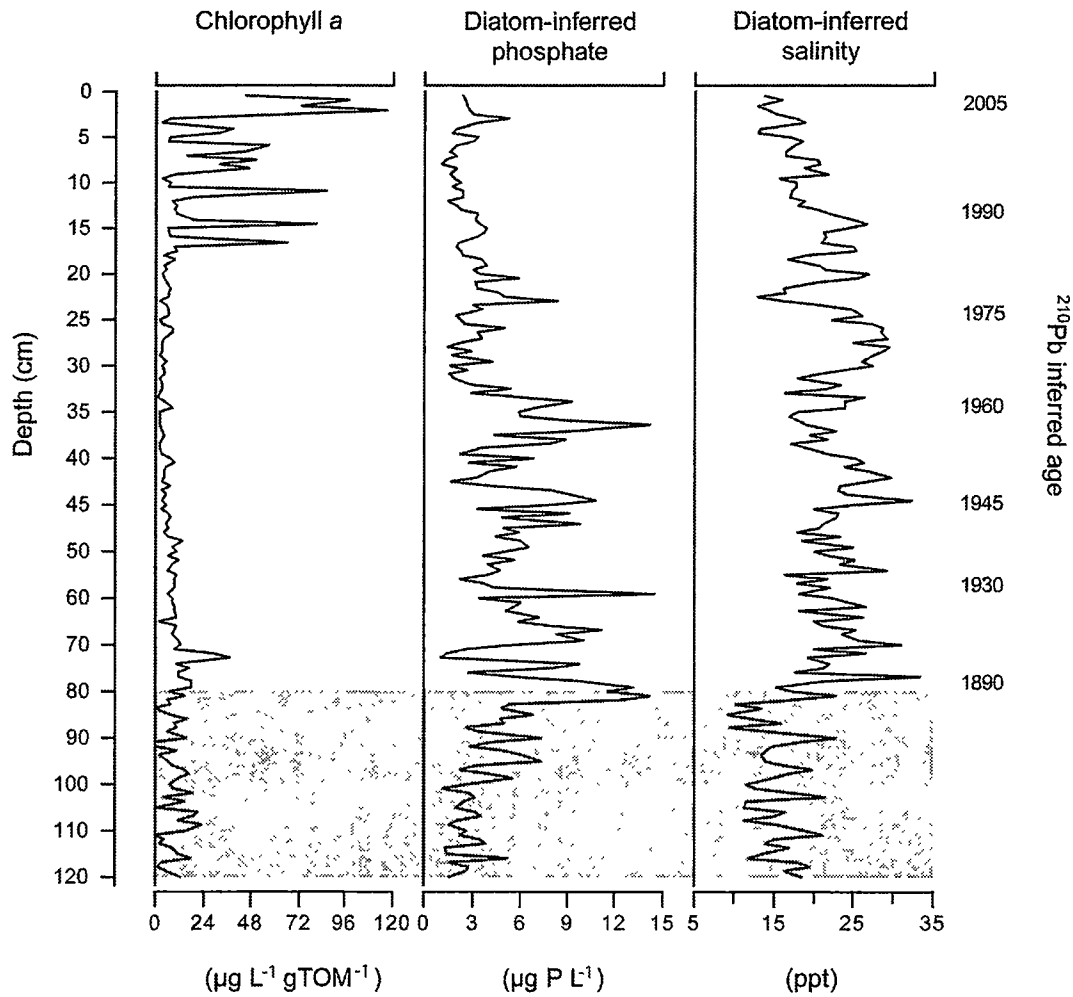


Figure 4.5: Measured sedimentary chlorophyll *a* and diatom-inferred phosphate and salinity in the Lake King sediment core. Pre-permanent entrance period indicated by grey shading. Note: TOM = total organic matter.

4.3.6 Chlorophyll a

Prior to the permanent entrance (i.e. pre 1889, which corresponds to 80-120 cm), chlorophyll *a* ranged from 0-23.0 µg L^{-1} $gTOM^{-1}$, with a mean of 9.36 µg L^{-1} $gTOM^{-1}$. From 1889 to 1980 chlorophyll *a* ranged from 1.42-37.25 µg L^{-1} $gTOM^{-1}$ with a mean of 7.03 µg L^{-1} $gTOM^{-1}$. From 1980-2005, chlorophyll *a* ranged from 3.46-649.3 µg L^{-1} $gTOM^{-1}$ with a mean of 51.24 µg L^{-1} $gTOM^{-1}$ with 9 main peaks (Figure 4.5).

4.4 Discussion

The aims of this Chapter were to apply the Victorian phosphate and salinity transfer functions developed in Chapter 3 to a sediment core from Lake King and use additional proxies (i.e. particle size and total sediment carbon, nitrogen and sulphur) to contribute information that will provide baseline data to assist the development of future management strategies.

4.4.1 Establishing baseline conditions

Prior to widespread European settlement and the opening of the permanent entrance, the diatom flora indicated that Lake King was a brackish water environment. The diatom assemblage was dominated by brackish *Cyclotella choctawhatceeana* and *C. striata*. The presence of *Cocconeis scutellum* var. *scutellum* at the base of the core also indicated that seagrass or other macrophyte cover was present before construction of the permanent entrance (Figure 4.4). The assemblage also included some marine species that are likely to have been present as a result of the natural opening of the lake to the sea, which intermittently occurred when the sand bar was breached (Bird 1965).

Relatively high sulphur content in the sediment indicated that at least some periods of hypoxia may have occurred prior to the construction of the permanent entrance (Figure 4.3). The presence of well-preserved, small sized taxa also suggests hypoxic conditions (Ellegaard *et al.* 2006) and possible periods of stratification. The cycling between benthic and planktonic species at the base of the core (Figure 4.4) pointed to periods of stratification and probable algal blooms, indicating that both were likely to have been features of the Lake King environment, a finding also supported by 19th century historical records (Stephens *et al.* 2004).

The increases in phosphate that occurred before the construction of the permanent entrance were preceded by peaks in *Cyclotella choctawhatceeana*. This is similar to findings by Weckström and Juggins (2006) from sites around the Baltic Sea where *Cyclotella choctawhatceeana* occurred in anthropogenically impacted sites, but did not cope with subsequent high nutrient environments. Increases in phosphorus have also been found in Danish lakes and attributed to

increased soil erosion and manuring of agricultural land (Bradshaw *et al.* 2006). This explanation may also apply to Lake King. Studies on the Murray-Darling river basin (Australia) have shown no trace of fertiliser-derived phosphorus, but found strong evidence of natural phosphorus entering the river due to accelerated erosion of subsoils and river banks (Davis & Kloop 2006). The extensive land clearing during the 19th century and subsequent accelerated erosion, together with the introduction of European-style agriculture during the 1800s, may similarly have contributed to rising phosphate concentrations in Lake King.

4.4.2 The impact of constructing a permanent entrance

Large changes in the ecology of Lake King occurred with the construction of the permanent entrance. Brackish planktonic species *Cyclotella choctawhatceeana* and *C. striata* dominated the planktonic taxa in the core. *Cyclotella choctawhatceeana* decreased after the construction of the permanent entrance and *Chaetoceros* spp. (a marine planktonic species) increased, however *C. choctawhatceeana* still remained a dominant component of the total sum of planktonic species, even with a clear increase in marine taxa. A similar trend was observed by McMinn *et al.* (2004) in the Hawksebury River, eastern Australia, where a reduction in freshwater inflow resulted in a reduction in the abundance of *Cyclotella* species from c. 1800 onwards, and an increase in marine planktonic taxa including *Chaetoceros* and *Thalassiosira* species. The benthic diatom flora also recorded the increase in salinity with the establishment of marine taxa including *Pleurosigma salinarium*, *Grammatophora oceanica* and *Catenula adherens* (Witkowski *et al.* 2000).

4.4.3 The nature and direction of environmental change in the 20th century

During the 20th century three main peaks in phosphate occurred (late 1930s, c. 1945 and late 1950s). The second peak corresponded with the introduction of artificial fertilisers into Australian agriculture (in 1951; Brodie 1995). A smaller peak in the 1970s coincided with a peak in *Skeletonema costatum*, which has been identified as an indicator species in other high nutrient environments (Weckström 2006). *Skeletonema costatum* is not often well preserved in coastal sediments,

however in the present core it became a dominant feature of the diatom assemblage in the 1970s. *Skeletonema costatum* is absent in the reference dataset, which suggests that the small increase in reconstructed phosphate at the time *Skeletonema costatum* peaks underestimates actual phosphate concentrations. This coincided with a reported shift in the ecology of upstream Lake Wellington, which, after a major drought in 1967/68, shifted from a macrophyte to phytoplankton dominated system (Webster & Harris 2004). It is possible that other areas of the Gippsland Lakes followed a similar trend (Simon Roberts, *pers. commun.* November 2006). Macrophytes are thought to keep nutrients sequestered in the sediment nutrient cycle and modulate nutrient pulses by drawing down water column nutrients (Harris 1999). A shift from macrophyte to phytoplankton dominance may have resulted in more nutrients being available from the sediment (McGlathery *et al.* 2001).

In recent years (i.e. from 1975 to present) phosphate and salinity generally declined, although phosphate has increased slightly from 2000-2002, while biological productivity (as indicated by sedimentary chlorophyll *a*) increased, resulting in at least 9 major peaks. It is thought that algal blooms naturally occur in Lake King, but that their frequency and biomass have increased in recent years (Chris Barry, *pers. commun.* October 2006). The chlorophyll *a* record supported this interpretation and provideed an indication of biological production over the last 100+ years (Figure 4.5). Biological production was slightly higher prior to the permanent entrance, but large peaks in chlorophyll *a* began to occur only from c. 1980 onwards. The occurrence of algal blooms has been recorded since the late 1970s, and while their timing is related to when they were reported rather than when they began (Stephens *et al.* 2004), many peaks in chlorophyll *a* recorded in the sediment since the 1980s correspond with known algal bloom events (Figure 4.6), although some are reported to have occurred when chlorophyll *a* values are low. The main peaks in chlorophyll *a* coincide with reported blooms of the cyanobacterium *Nodularia spumigena* (Stephens *et al.* 2004, Figure 4.6).

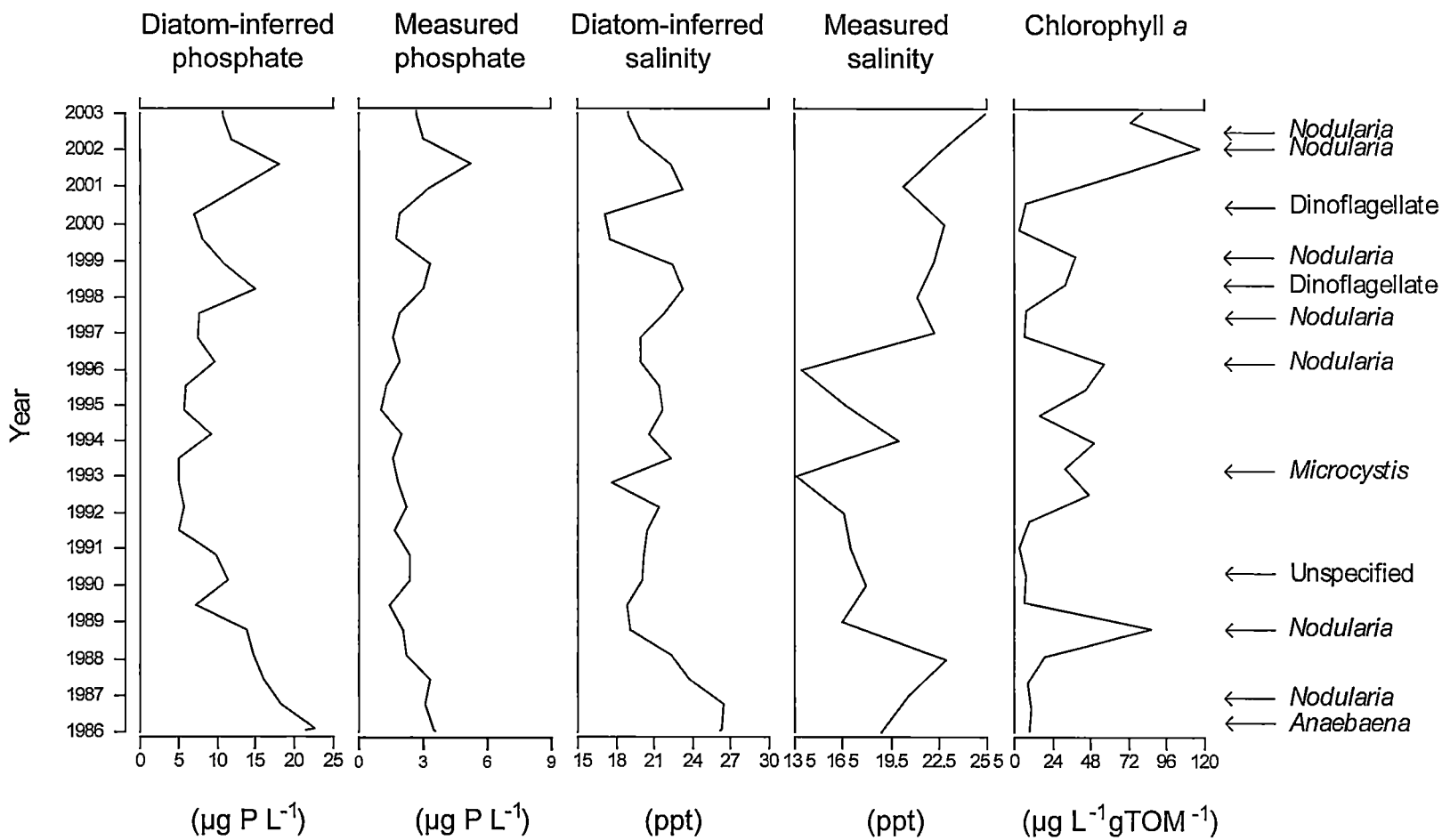


Figure 4.6: Diatom-inferred and measured phosphate and salinity from monitoring data (1986-2003). Measured sedimentary chlorophyll *a* and known algal bloom occurrences are also indicated.

4.4.4 Implications for future management

This study has shown that the Gippsland Lakes have experienced extensive environmental changes since European settlement, in particular since the establishment of the permanent entrance, which caused a shift from a brackish-water to marine diatom flora.

Despite the establishment of the permanent entrance, the diatom assemblages, chlorophyll *a* concentrations and sulphur contents all indicate that stratification and algal blooms are likely to have been a natural feature of Lake King throughout the period represented by the core. This raises some important management implications regarding the environmental objectives of managing Lake King, which are to prevent or reduce algal blooms, as well as the feasibility and cost of various management options. There is substantial debate as to whether, in a modified system such as the Gippsland Lakes, management should aim to return the system to as near as possible to its 'natural' or pre-European state, or whether environmental objectives focussed on meeting stakeholder needs are more appropriate (Webster *et al.* 2001).

In the case of the Gippsland Lakes, the main management strategy is to reduce nutrient loads and improve water quality. Part of this strategy involves reducing the frequency and severity of algal blooms. However, recent large peaks in chlorophyll *a* do not correspond to high water column phosphate as inferred by the diatoms. Phosphate was much higher during the mid 20th century than in recent years, so the link between nutrients and algal blooms is not well established. This suggests that other factors are involved. It is possible that relatively dry years since 1980 have contributed to greater stratification and light penetration, which are important to Australian algal bloom occurrence (Davis & Kloop 2006). To establish baseline conditions, further work is needed to investigate pre-permanent entrance algal blooms in terms of type, frequency and extent, particularly in relation to *Nodularia spumigena*, which is currently the most common blooming cyanobacterial species. This could be achieved using HPLC analyses of sedimentary cyanobacterial carotenoids and their breakdown products (e.g. Hodgson *et al.* 1998a).

4.4.5 Evaluation of phosphate and salinity reconstructions: monitoring versus palaeolimnological data for Lake King from 1986-present

Monthly measurements (summarised as annual averages of measurements made in surface waters) of phosphate and salinity in Lake King have been made by the Victorian Environment Protection Agency from 1986 to present (Figure 4.6). High phosphate values were recorded in 1988 (27.5 μg P L^{-1}) and from 1999-2001 (max. 18 μg P L^{-1}). Salinity was high in 1988 (22.5 ppt), 1994 (21 ppt) and > 20 ppt since 1997. Low salinity values were measured in 1993 (13.5 ppt) and 1996 (14 ppt, Figure 4.6).

Diatom-inferred phosphate and salinity trends for the same period represent values integrated over a period of approximately 8 months (i.e. sample interval of 0.5 cm / ^{210}Pb inferred accumulation rate of 0.74 x 12 months = 8.1) and thus constitute data from which longer-term trends can be identified.

Measured and reconstructed phosphate trends are similar. Both decline from 1986-1990 and have small peaks at the same time in 1990, 1994, 1996, 1998-1999 and mid 2001. However, while the trends are similar, measured phosphate is consistently higher (by approximately three times) than diatom-inferred phosphate. This suggests that the transfer function underestimates actual phosphate concentrations. This has implications for the larger peaks in phosphate in the 1930s, c. 1945 and late 1950s, suggesting that actual phosphate concentrations may have been higher than the concentrations inferred from the diatom-phosphate transfer function (Figure 4.5). Measured and inferred salinity follow similar trends from 1986-1999. Both recorded higher salinity c. 1988 before decreasing c. 1989 and again c. 1993. From 1999-2003 they showed opposite trends (Figure 4.6).

4.4.6 Value of a palaeolimnological approach for coastal ecosystem management

Tackling the increasing problem of declining water quality in coastal waters is an internationally important issue. As urban populations continue to expand, land clearing for agriculture also continues and consequently nutrient input from erosion and fertiliser use occurs, this problem will only be exacerbated. Deciding

on the appropriate management of coastal lakes, lagoons and estuaries is a difficult task. Successful management, whether the aim is conservation, restoration, or 'sustainable wise-use', requires the identification of baseline conditions, rates and extent of change. Climate variability and predicted climate changes also need to be considered as future changes may mean it is not possible to restore sites to their 'natural' or in the case of Australia, pre-European impact status, particularly at coastal sites where sea level rise is an important management consideration. Attempting to restore and return an ecosystem to what it once was may not be ecologically or economically practical.

Current Australian and New Zealand guidelines for fresh and marine water quality state that defining baseline conditions that provide a target for management actions and a meaningful comparison for monitoring programs is necessary (NLWRA 2000). There are guidelines on how to define these baseline conditions, however they are based on finding nearby relatively 'undisturbed' sites and using these to determine generalised baseline conditions. However, in many cases there are no nearby sites that are suitable for the site of interest. In the absence of long term monitoring, a palaeolimnological approach offers the only way to determine these baseline conditions on a site-by-site basis.

4.5 Conclusions

This study has provided valuable information on the past ecology of Lake King, the impact of the permanent entrance and changes in phosphate and salinity over the last 100+ years, together with evidence that supports the presence of algal blooms throughout the record. Changes in diatom assemblages document a shift from a brackish-water to marine diatom flora since the construction of the permanent entrance. Concentrations in phosphate increased at the same time and experienced peaks in the 1930s, c. 1945 and late 1950s. Clear increases in chlorophyll *a* have also occurred since the 1980s (to a maximum of 120 $\mu g\ L^{-1}$ $gTOM^{-1}$), likely associated with an increase in the frequency and intensity of algal blooms. Collectively these data show that the ecology of Lake King is now very different to that present during early European settlement.

Quantitative relationships between benthic diatom assemblages and water chemistry in Macquarie Island lakes and the development of transfer functions

The work presented in this Chapter has been submitted as:
Saunders K.M., Hodgson D.A. & McMinn A. (2008) Quantitative relationships between benthic diatom assemblages and water chemistry in Macquarie Island lakes and their potential to reconstruct past environmental changes. *Antarctic Science*. doi:10.1017/S0954102008001442.

5.1 Introduction

Macquarie Island, located at 54°30'S, 158°57'E, is one of the few landmasses situated in the Southern Ocean (Figure 5.1). It is located just north of the Antarctic Convergence, 1500 km southeast of Tasmania, 1200 km southwest of New Zealand and 1300 km from the Antarctic continent. It is 34 km long, 5 km at its widest and has an area of 120 km^2 (Figure 5.1).

Macquarie Island is a rare example of uplifted oceanic crust and is part of the Macquarie Island Ridge Complex that runs south from New Zealand (Davis 1988). Faulting, uplift, sea level changes, erosion and periglacial processes have been the major factors shaping Macquarie Island and its lakes (Selkirk *et al.* 1988). While the occurrence of past glacial activity has been debated, it is now believed that glaciation did not play a significant role in shaping the current landscape (Selkirk *et al.* 1990), although it is still debatable if permanent snow and ice accumulated in some areas during the Last Glacial Maximum (McGlone 2002).

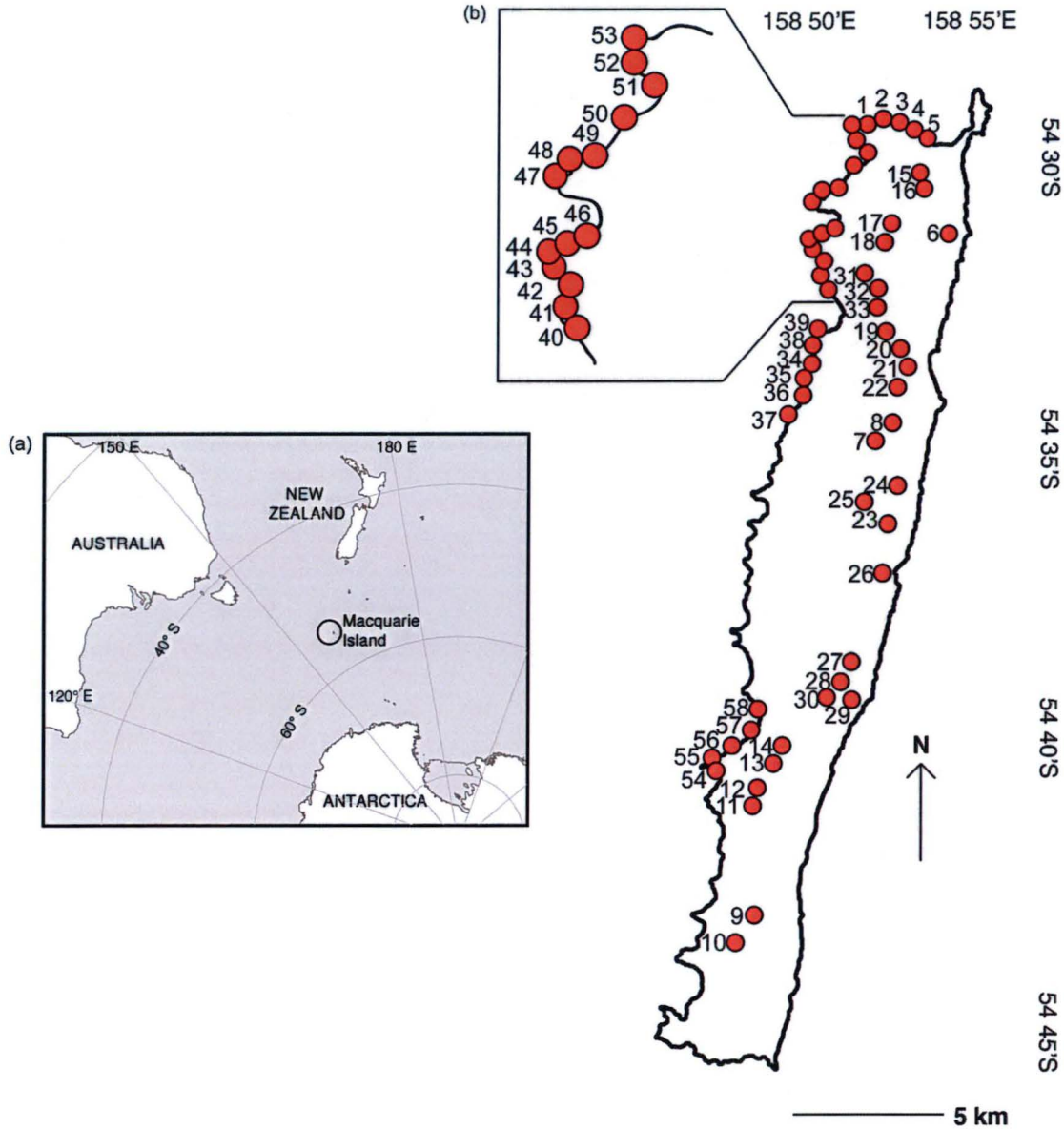


Figure 5.1: (a) Location of Macquarie Island and (b) location of sampling sites on Macquarie Island for the reference dataset.

The island experiences a cool, wet and windy oceanic climate with small annual and diurnal variations in temperature. The weather is dominated by westerly to north-westerly winds with a mean annual wind speed of ~ 30 km hr^{-1}, reaching gale forces of up 170 km hr^{-1}. Mean annual precipitation is 920 mm and it rains > 300 days per year (BOM 2007). Due to almost constant cloud cover, light levels are generally low, with a mean annual average of 2.2 hours of sunshine per day (BOM 2007). Mean monthly temperature ranges between 4.9 °C in winter and 8.8 °C in summer, with a daily variation of ~ 3.5 °C (BOM 2007).

The island is a narrow plateau with steep sides (generally 20-40°) rising directly from the coast or raised beach terraces and averages 250-300 m above sea level, with its highest point at 433 m. Macquarie Island is extensively vegetated with tussock grasslands, herbs and sedges, areas of peat, mosses, liverworts and lichens, but there are no trees (Figure 5.2).

The island is also home to abundant wildlife, providing a vital refuge and important breeding ground in a region of sparse landmasses (Figure 5.3). In recognition of its geological and wildlife values, Macquarie Island has been designated as a Sanctuary (1933), a Tasmanian State Reserve (1978), World Heritage Area (1997) and United Nations Educational, Scientific and Cultural Organisation Biosphere Reserve (the only Biosphere Reserve in the sub-Antarctic biogeographic region). The adjacent seas are designated as a Marine Park and form the second largest Marine Protected Area in the world.

The importance of the Southern Ocean in global climate is increasingly being recognised (Rintoul *et al.* 2001) and Macquarie Island is ideally positioned to provide valuable insights into Southern Hemisphere climate change, particularly in the sub-Antarctic region. To date, there have been few attempts to reconstruct past climate changes at Macquarie Island and more generally in the region south of 45°. This is surprising, as sub-Antarctic islands are well placed to respond to changes in rainfall, temperature and westerly wind strength associated with changes in the thermal gradient between temperate and polar latitudes, the position of the Polar Frontal Zone (PFZ) and sea ice.

(a)

(b)

(c)

Figure 5.2: (a) West coast of Macquarie Island looking north; (b) west coast of Macquarie Island looking south; and (c) central plateau looking south.

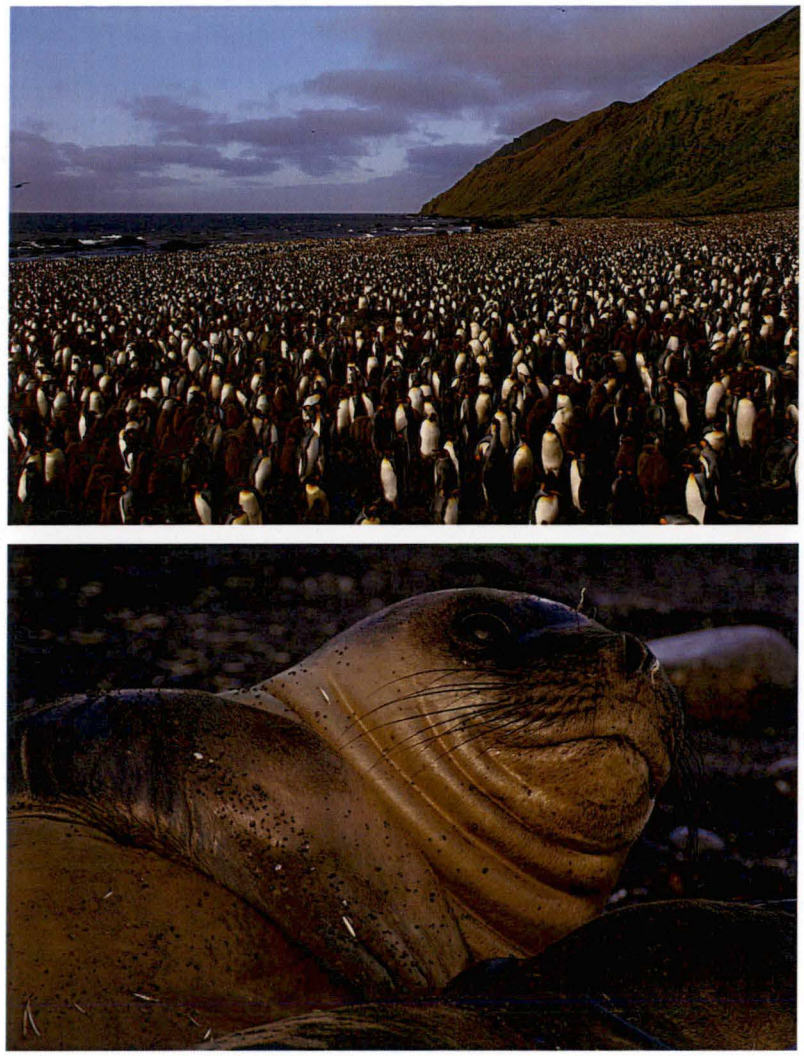


Figure 5.3: Abundant wildlife on Macquarie Island.

Macquarie Island has the longest record of meteorological observations for the South Pacific and South Indian Southern Ocean region (records began in 1949; BOM 2007) and forms one of a chain of meteorological stations from Antarctica to the subtropics. Consequently, it is ideally situated to provide vital data for global weather predictions and climate modeling. However, Macquarie Island, like other sub-Antarctic islands, has been extensively damaged by feral animals since the arrival of humans in 1810.

Early interest in the island was purely commercial, based on exploitation of penguin and seal resources (Davis 1988). During this period a number of alien vertebrate species were introduced to the island including cats (*Felis catus,* 1820s), European rabbits (*Orycolagus cuniculus*, 1870s), weka (*Gallirallus*

australis scotti, 1870s), house mice (*Mus musculus*, 1890s) and ship rats (*Rattus rattus*, 1900; Copson & Whinam 2001).

In 1919, the commercial exploitation of penguins and seals was terminated (Brothers & Copson 1988), but introduced species continue to threaten Macquarie Island's fragile habitats and conservation status. Cats and weka have recently been eradicated (2000 and 1989 respectively; PWS 2007), but this has intensified damage by rabbits, particularly through vegetation disturbance and erosion (Figure 5.4). This impact makes it difficult to assess the responses of the island and its biota to observed climate changes since meteorological observations began and a longer temporal perspective is needed.

Macquarie Island is characterised by abundant shallow and deep ponds and lakes (Evans 1970). Oceanic spray is the principal source of ions to the lakes, with geochemical weathering playing a minor role (Buckney & Tyler 1974). The ion chemistry of the lakes is consequently influenced by the prevailing westerly winds and distance from the ocean, and seasonal variation in chemical composition is small (Buckney & Tyler 1974, Bryden 1988).

Shallow lakes, in particular, are highly sensitive to environmental changes, which make them idea for palaeolimnological studies and assessing climate change and feral animal impacts (Verleyen *et al.* 2003, Smol & Douglas 2007).

Figure 5.4: Rabbit damage on Macquarie Island (centre photo expanded below).

The rapid rate of climate change in the high latitudes is well documented (Pienitz *et al.* 2004, Smol & Douglas 2007) and high latitude regions are considered to be valuable, sensitive locations for determining the rate of climate change and provide a basis for predicting the likely consequences of future anthropogenic-driven climate change (Smol & Douglas 2007). High latitude diatom-based transfer functions have previously been developed for inferring nutrients (e.g. Lim *et al.* 2007), salinity (Verleyen *et al.* 2003, Sabbe *et al.* 2004, Hodgson *et al.* 2006b), pH (e.g. Jones & Birks 2004), chlorophyll *a* (e.g. Jones & Juggins 1995), temperature (e.g. Kumke *et al.* 2004, Gremmen *et al.* 2007) and soil moisture content (e.g. Van de Vijver *et al.* 2002b). To date, with the exception of Van de Vijver *et al.* (2002a) and Gremmen *et al.* (2007), there are no diatom-based transfer functions from the sub-Antarctic despite good evidence that the composition of diatom assemblages in this region is strongly influenced by environmental gradients (e.g. Van de Vijver *et al.* 2002a, 2004, 2005). The relationships between diatom community composition and environmental factors on Macquarie Island have not yet been fully explored.

5.2 Aims

The Aims of this Chapter are to:

1. Determine the major environmental gradients occurring in Macquarie Island lakes;
2. Provide baseline, species-level data on the composition and distribution of surface sediment diatom communities of Macquarie Island lakes;
3. Investigate and identify the environmental gradients influencing diatom distribution in Macquarie Island lakes;
4. Develop transfer functions based on these environmental variables.

5.3 Results

Water and surface sediment samples were collected from 58 sites in 50 ponds and lakes on the coastal terrace and plateau on Macquarie Island, and used to develop a diatom reference dataset to investigate major environmental gradients, diatom-environment relationships and determine which environmental variables could potentially be used to develop transfer functions.

5.3.1 Limnology

The sites were sampled from February to April 2006. Table 5.1 outlines the environmental data measured at each site. The lakes were all freshwater and conductivity ranged from 0-1571 μS cm^{-1} (mean 343 μS cm^{-1}). The nutrient status of sites varied from oligotrophic to highly eutrophic. Soluble reactive phosphate (SRP) ranged from 0-9890 μg P L^{-1} (mean 538.1 μg P L^{-1}); nitrate/nitrite ranged from 0.15-8578 μg N L^{-1} (mean 831.1 μg N L^{-1}); and silicate ranged from 2.15-2706 μg Si L^{-1} (mean 370.1 μg Si L^{-1}). Sites ranged from acidic (pH 5.5) to alkaline (pH 9.95) with a mean of pH 7.15. Dissolved oxygen ranged from 4.73-18.08 mg L^{-1} (mean 11.43 mg L^{-1}), temperature ranged from 4.49-13.48 °C (mean 7.65 °C) and turbidity ranged from 6-2724 NTU (mean 121.6 NTU). The highest nutrient, conductivity and turbidity measurements were made in coastal sites. Coastal sites also had a greater dissolved oxygen range than inland sites, but the latter had a greater pH range (Table 5.1).

Table 5.1: Environmental data recorded from Macquarie Island lakes. c = coastal lake (i.e. within the coastal terrace), i = inland lake (i.e. above the coastal terrace), Temp = Temperature, SpCond = specific conductivity, DO = dissolved oxygen, Si = silicate, SRP = soluble reactive phosphate, N = nitrate/nitrite.

Site no.	Type	Easting °	Northing °	Temp °C	pH	SpCond µS cm^{-1}	DO mg L^{-1}	Turb NTU	Si µg Si L^{-1}	SRP µg P L^{-1}	N µg N L^{-1}
1	c	54.49801	158.89277	10.83	5.74	522	10.23	146	31.1	294	263
2	c	54.49756	158.89295	10.24	6.26	608	4.73	58	108	1951	3545
3	c	54.49858	158.89591	9.28	7.07	559	10.17	32	177	381	1514
4	c	54.49914	158.89988	9.30	7.40	555	10.40	391	415	261	4636
5	c	54.50115	158.90539	9.70	7.40	406	10.66	7	365	24.3	7.45
6	i	54.53467	158.92851	13.48	9.95	255	12.33	9	11.8	189	33.6
7	i	54.59812	158.88959	8.44	6.47	164	11.11	6	2.15	0.00	0.98
8	i	54.59696	158.89094	8.47	6.48	164	11.09	7	2.88	0.22	1.88
9	i	54.74277	158.82093	7.39	7.46	224	11.35	9	65.9	1.99	5.80
10	i	54.74521	158.82238	7.35	7.21	223	11.50	16	73.2	3.97	4.91
11	i	54.69969	158.82231	6.93	6.35	215	11.52	10	5.65	1.40	7.65
12	i	54.69760	158.81993	6.74	6.52	215	11.55	9	3.15	0.64	3.29
13	i	54.69107	158.82110	7.45	7.10	265	11.27	9	8.91	2.27	0.72
14	i	54.68538	158.82715	7 87	7.08	265	11.33	10	11.8	3.34	5.61
15	i	54.51734	158.91162	4.86	6.59	183	12.07	12	24.1	4.81	30.1
16	i	54.51819	158.91068	5.86	6 98	179	11.66	7	69.5	24.5	15.5
17	i	54.52837	158.89000	5.44	6.83	179	12.06	9	193	0.67	0.15
18	i	54.53222	158.88823	5.49	7.01	179	11 80	8	92.3	0.04	4.75
19	i	54.57007	158.89847	7.03	8.72	280	12.16	276	821	93.1	14.7
20	i	54.57212	158.89840	7.10	8.75	278	11.81	16	648	163	126
21	i	54.57756	158.89553	6.64	6.84	164	11.69	31	7.03	0.73	9.51
22	i	54.58024	158.89326	6.40	6.79	164	11.61	7	2.80	0.28	1.27
23	i	54.61470	158.89090	7.50	7.33	146	11.81	7	14.1	4.56	2.25
24	i	54.61429	158.89200	8.16	7.40	139	11.70	6	68.2	2.94	9.68
25	i	54.61585	158.89205	7.79	6.85	116	11.54	9	9.19	5.35	8.57
26	i	54.63104	158.89502	8.29	7.26	209	11.34	9	1525	61.8	21.1
27	i	54.66061	158.87287	11.74	6.28	0	10.36	84	4.11	0.00	3.75
28	i	54.66180	158.87127	10.82	6.44	0	10.85	18	2.74	1.35	2.41
29	i	54.67283	158.87064	7.13	5.99	120	11.82	21	31 1	7.82	23.8
30	i	54.67038	158.87014	7.34	7.50	156	11.86	7	4.66	3.39	8.06
31	i	54.54617	158.88183	4.58	7 56	248	13.02	21	12.3	120	7.98
32	i	54.54567	158.88119	4.50	7.39	247	13.01	20	5 90	18.1	15 6
33	i	54.54518	158.88301	4.49	7.36	248	13.02	30	16.9	13.1	13.5
34	c	54.56676	158.85851	6.83	7.57	909	11.78	8	202	155	68.7
35	c	54.57084	158.86057	7.48	6.27	528	7.26	974	918	78.1	41.7

Table 5.1 *cont.*

Site no.	Type	Easting °	Northing °	Temp °C	pH	SpCond µS cm^{-1}	DO mg L^{-1}	Turb NTU	Si µg Si L^{-1}	SRP µg P L^{-1}	N µg N L^{-1}
36	c	54.57057	158 85978	7.48	7.03	625	12.25	26	1596	240	3327
37	c	54.56913	158 85861	8.57	6.73	1136	9.17	214	73.9	1029	181
38	c	54.56419	158.85704	6.33	7.47	1482	11.91	9	170	527	636
39	c	54.56396	158.85698	5.45	7.82	1528	12.24	95	43.3	497	207
40	c	54.55201	158.87249	6.24	6.08	552	8.13	21	86.4	205	119
41	c	54.54915	158.87012	5 79	7 19	495	11.12	7	1090	17.2	154
42	c	54.54048	158.86370	5.61	7.23	525	11.95	8	499	151	33.6
43	c	54.53821	158.86302	5.29	6.61	2	10.97	12	72.1	917	1186
44	c	54.53344	158.85731	6.32	7 25	1502	12.14	20	72.3	1461	6461
45	c	54.53161	158.86064	6.02	6.66	1244	10.75	9	505	9890	160
46	c	54.51984	158.86641	8.03	7.32	693	11.48	21	2459	1250	188
47	c	54.52044	158.86950	8.73	7.46	698	12.03	28	291	1558	5240
48	c	54.51947	158.86957	8.89	8.12	603	14 43	30	2706	217	28.5
49	c	54.51251	158.87575	13.13	8.13	732	13.59	1042	441	415	84.8
50	c	54.51232	158.87611	10.01	7.85	1265	11.21	2724	1064	774	625
51	c	54.51255	158.87656	8.16	7.28	1094	9.55	247	989	672	1947
52	c	54.51226	158.87887	7 78	7.41	710	11.98	81	695	571	126
53	c	54.50478	158.88744	9 41	9.13	769	18.08	10	1975	369	1839
54	c	54.68750	158.80718	6 75	6.77	1176	11.51	6	99.5	808	1052
55	c	54.68803	158.80679	6.93	5.50	1478	10.44	10	78.7	101	117
56	c	54.68375	158.81710	7 61	6.61	646	10.97	36	96.2	2249	1936
57	c	54.68244	158.81971	7.31	6.69	1571	8 71	83	120	2806	8578
58	c	54.67582	158.82960	8.76	8.36	749	14.66	16	286	612	3523
All sites			Mean	7.65	7.15	527	11.43	122	370	538	831
			Median	7 42	7.15	343	11.55	16.0	82.6	111	33.6
			Min	4.49	5.50	0.0	4.73	6.0	2.2	0.0	0.2
			Max	13.48	9.95	1571	18.08	2724	2706	9890	8578
Coastal sites			Mean	7.94	7.15	845	11.15	212	591	1016	1594
			Median	7.70	7.24	704	11.17	27.0	288	512	444
			Min	5.29	5.50	2 0	4 73	6.0	31.1	17.2	7.5
			Ma	13.13	9.13	1571	18.08	2724	2706	9890	8578
Inland sites			Mean	7.33	7.16	187	11.72	24.4	134	26.0	13 7
			Median	7.24	7.05	181	11.68	9.0	12.0	3.4	7.8
			Min	4.49	5 99	0.0	10.36	6.0	2.2	0.0	0.2
			Max	13.48	9.95	280	13.02	276	1526	189	126

5.3.2 Diatoms

A list of diatom species including occurrence and distribution is presented in Appendix 5. Images of the taxa are in Appendix 6. In total, 208 diatom species were identified from 34 genera. Only those species occurring with a maximum relative abundance of ≥ 1% were included in the statistical analyses (129 taxa). These taxa represent 96.5-100% (mean 99.1%) of the total diatom count for each sample site.

Thirteen taxa were abundant in the calibration set, occurring with ≥ 50% relative abundance in at least one lake. Sixteen taxa were common, occurring in ≥ 15 samples and 7 of these were both dominant and common: *Stauroneis* sp. 1, *Planothidium quadripunctatum*, *Staurosira venter*, *Psammothidium abundans*, *Fragilaria capucina* and Unknown sp. 1 (Table 5.2).

Different diatom assemblages were present in inland lakes compared to coastal lakes. Inland lakes were dominated (i.e. species occurring with ≥ 10% maximum abundance and in ≥ 10 samples) by *Aulacoseira distans*, *Cavinula pseudoscutiformis*, *Cocconeis pediculus*, *Diatomella* cf. *balfouriana*, *Fragilaria capucina*, *Navicula* sp. 1, *Planothidium quadripunctatum*, *Psammothidium abundans*, *Stauroneis* sp. 1 and Unknown sp. 1. In contrast, the coastal lakes were dominated by *Fragilaria capucina*, *Planothidium delicatulum*, *Planothidium lanceolatum* and *Planothidium quadripunctatum*. Only *Fragilaria capucina* and *Planothidium quadripunctatum* were dominant in both coastal and inland lakes.

Table 5.2: Abundant species (i.e. species occurring with a maximum relative abundance ≥ 50%) and common species (i.e. species occurring in ≥ 15 samples) in the Macquarie Island dataset. Species in bold are both. Note: n = number of occurrences, Max = maximum relative abundance, Mean(adj) = non-zero mean, Med = median, Med(adj) = non-zero median.

Species	Code	n	Max %	Mean %	Mean(adj) %	Med %	Med(adj) %
Species occurring with ≥ 50% relative abundance at a site							
Aulacoseira distans	CEN16	5	50.0	1.12	13.27	0.00	4.59
***Aulacoseira distans* (var. 1)**	**CEN16a**	**15**	**75.2**	**3.21**	**12.64**	**0.00**	**4.36**
Achnanthes* cf. *subexigua	**ACHsub**	**31**	**62.5**	**3.72**	**7.08**	**0.17**	**2.94**
Brachysira styriaca	**NAV32c**	**15**	**74.3**	**3.51**	**13.80**	**0.00**	**1.71**
Cyclotella meneghiniana	CEN15	5	52.9	0.96	8.07	0.00	0.44
Eunotia flexuosa	UNK57b	6	56.3	1.33	13.07	0.00	3.09
Fragilaria capucina var. 1	FRAcap2	4	79.5	1.41	20.87	0.00	1.83
Fragilaria* cf. *subsalina	**FRA8**	**33**	**97.9**	**25.07**	**44.82**	**1.80**	**39.46**
Navicula cryptotenella	NAV63	13	52.7	1.75	7.93	0.00	3.00
Planothidium delicatulum	**ACH26**	**17**	**81.3**	**5.42**	**18.83**	**0.00**	**1.83**
Planothidium hauckianium	**PLAhau**	**24**	**70.4**	**6.12**	**15.06**	**0.00**	**3.28**
Psammothidium abundans	**ACHsub2**	**24**	**95.1**	**8.90**	**21.88**	**0.00**	**12.70**
Species occurring at ≥ 15 sites							
Diatomella cf. *balfouriana*	UNK37b	15	11.74	0.71	2.78	0.00	1.67
Encyonema vulgare	AMP18a	15	6.98	0.51	2.33	0.00	1.69
Gomphonema angustatum	GOMang	15	6.10	0.45	2.05	0.00	1.47
Luticola cf. *mutica*	ACH25	17	28.8	0.87	3.01	0.00	0.99
Pinnularia lecohui	NAV55	15	2.94	0.26	1.16	0.00	0.86
Planothidium cf. *aueri*	PLAfre3	17	24.2	1.05	3.44	0.00	0.75
Opephora marina	OPE3	24	17.9	1.59	3.92	0.00	2.84
Planothidium frequentissimum	PLAfre	25	27.9	1.56	3.80	0.00	0.99

5.3.3 Multivariate analyses

Multivariate analyses were used to determine major environmental gradients in the dataset and identify potential environmental variables for developing transfer functions.

(a) Environmental data

Principal Components Analysis (PCA) of the environmental data indicated that nearly 50% of the variation in the environmental data was captured by the first two principal components (Table 5.3). Variation along the first axis was explained by conductivity, nutrients and turbidity, with high nutrient and conductivity sites on the left hand side, and low nutrient and conductivity sites on the right hand side of the biplot. Variation along the second axis was explained by pH and dissolved oxygen (Figure 5.5). The distribution of coastal and inland sites in Figure 5.6 clearly illustrates the oceanic source and importance of conductivity and nutrients to the lakes.

Table 5.3: Principal Components Analysis of the Macquarie Island dataset.

Axes	1	2	3	4	Total
variance					
Eigenvalues	0.312	0.169	0.123	0.058	1.000
Cumulative % variance of environmental data	31.2	48.1	60.4	66.2	

(b) Diatom-environment relationships

Canonical Correspondence Analysis (CCA) indicated that the environmental variables explained 26.9% of the variation in the diatom data (Table 5.4). As all VIFs were < 10, all environmental variables were retained. The ordination plot indicated that SRP was highly correlated to axis 1, while the remaining variables were correlated to both, but nitrate/nitrite and conductivity lay closer to axis 1,

while silicate was in between, and pH and dissolved oxygen were closer to axis 2 (Figures 5.6-5.7).

Table 5.4: Canonical Correspondence Analysis results of the Macquarie Island dataset with all environmental variables. Note: $\sum$ = sum.

Axes	1	2	3	4
Eigenvalues	0.556	0.250	0.156	0.117
Cumulative % variance of species data	9.95	14.49	17.54	19.77
$\sum$ all canonical eigenvalues	1.376			
$\sum$ all eigenvalues	5.112			

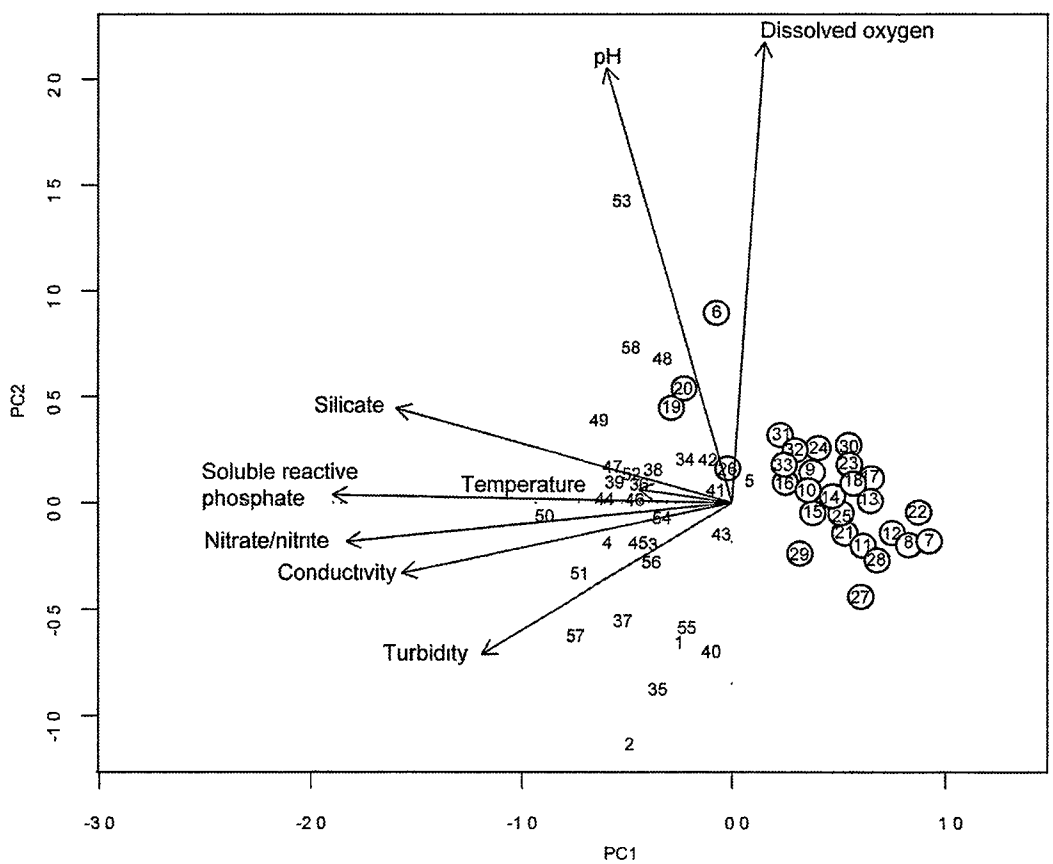


Figure 5.5: Principal Components Analysis of the environmental data in the Macquarie Island dataset. Note: sites with circles are inland sites. See Table 5.1 for site locations.

CCAs of each environmental variable alone were performed (Table 5.5), followed by CCAs of individual environmental variables with the remainder as covariables to determine which made independent, significant contributions to explaining variation in the species data (i.e. $p < 0.05$, based on Monte Carlo permutation tests). This led to (in order) the removal of nitrate/nitrite, turbidity and dissolved oxygen, leaving conductivity, pH, silicate, SRP and temperature as the environmental variables that explained independent portions of the variance in diatom species distribution.

CCA of these variables indicated that they explain 21.7% of the variance in the species data and axes 1-4 explain 10.9%, 4.4%, 2.7% and 2.0% respectively (Figures 5.8-5.9, Table 5.6).

Variance partitioning indicated there was a lot of interaction between conductivity, silicate and SRP, and that most of the interaction was due to silicate (Table 5.7).

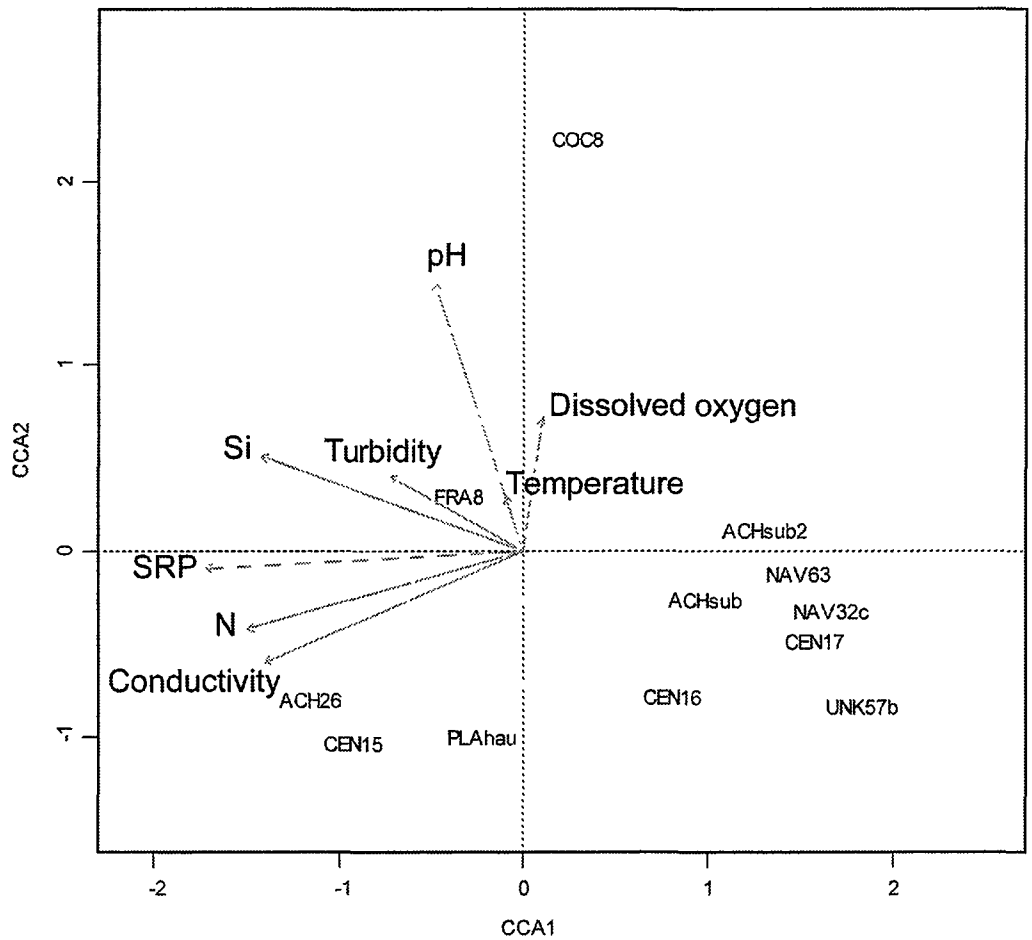


Figure 5.6: Canonical Correspondence Analysis of the Macquarie Island dataset with all environmental variables. Dominant species displayed (i.e. species occurring with ≥ 20% relative abundance and occurring in ≥ 5 samples). Note: N = nitrate/nitrite, SRP = soluble reactive phosphate, Si = silicate. See Appendix 5 for a list of species names.

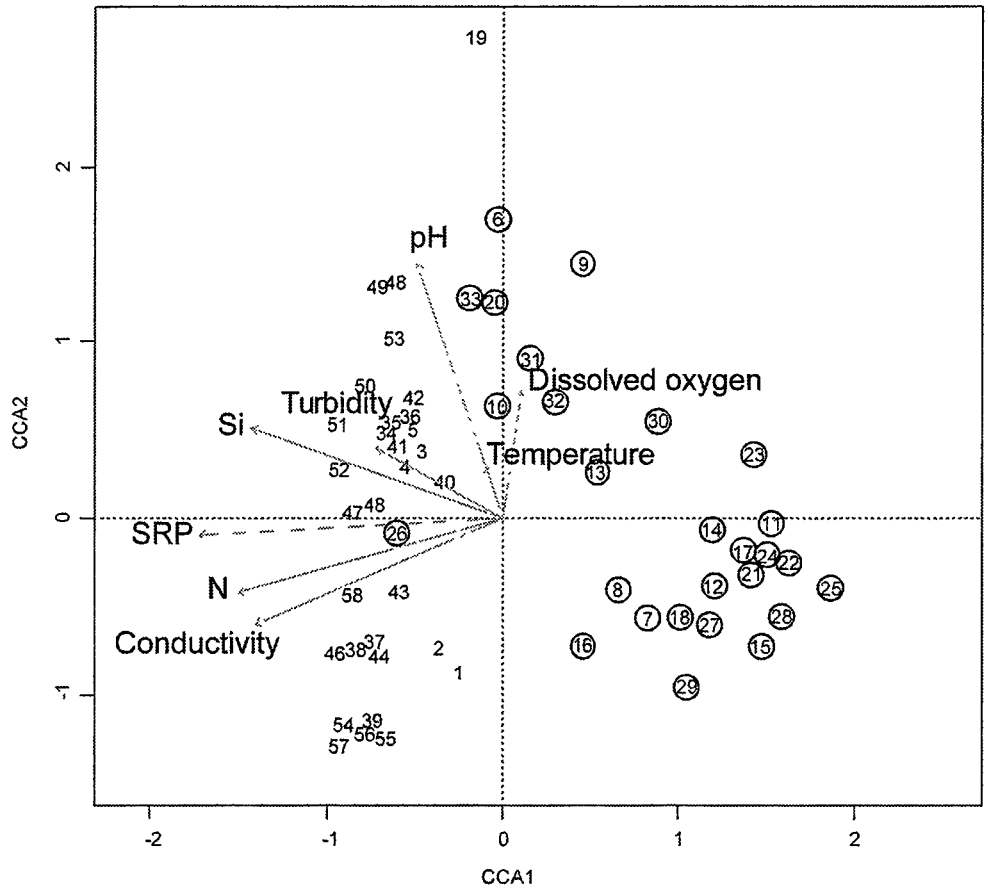


Figure 5.7: Canonical Correspondence Analysis of the Macquarie Island dataset with all environmental variables. Sites displayed. Inland sites are circled. Note: N = nitrate/nitrite, SRP = soluble reactive phosphate, Si = silicate. See Table 5.1 for site locations.

Table 5.5: Individual Canonical Correspondence Analysis results. Note: SRP = soluble reactive phosphate, $\sum$ = sum.

Environmental variable	$\sum$ canonical eigenvalues	% variance explained	p value
Conductivity	0.423	8.3	<0.005
Dissolved oxygen	0.128	2.5	0.082
Nitrate/nitrite	0.441	8.6	<0.005
pH	0.206	4.0	<0.005
Silicate	0.380	7.4	<0.005
SRP	0.529	10.3	<0.005
Temperature	0.136	2.7	0.039
Turbidity	0.178	3.5	0.005

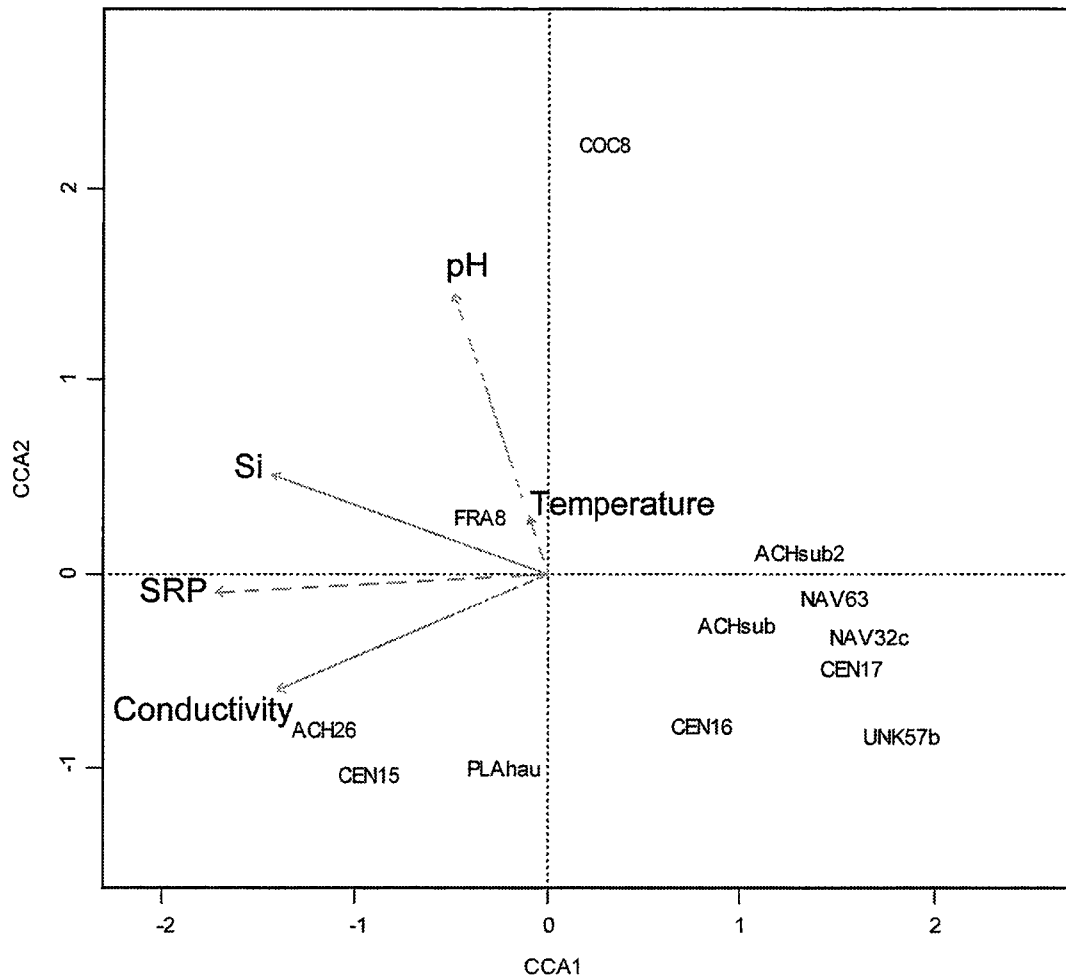


Figure 5.8: Canonical Correspondence Analysis of the Macquarie Island dataset with forward selected variables. Dominant species (i.e. species occurring with a maximum relative abundance ≥ 20% and occurring in ≥ 5 samples) displayed. Note: Si = silicate, SRP = soluble reactive phosphate. See Appendix 5 for a list of species names.

Table 5.6: Canonical Correspondence Analysis results of the forward selected variables in the Macquarie Island dataset (i.e. conductivity, pH, soluble reactive phosphate, silicate and temperature). Note: ∑ = sum.

Axis	1	2	3	4
Eigenvalues	0.556	0.227	0.139	0.103
∑ canonical eigenvalues	1.108			
∑ all eigenvalues	5.112			

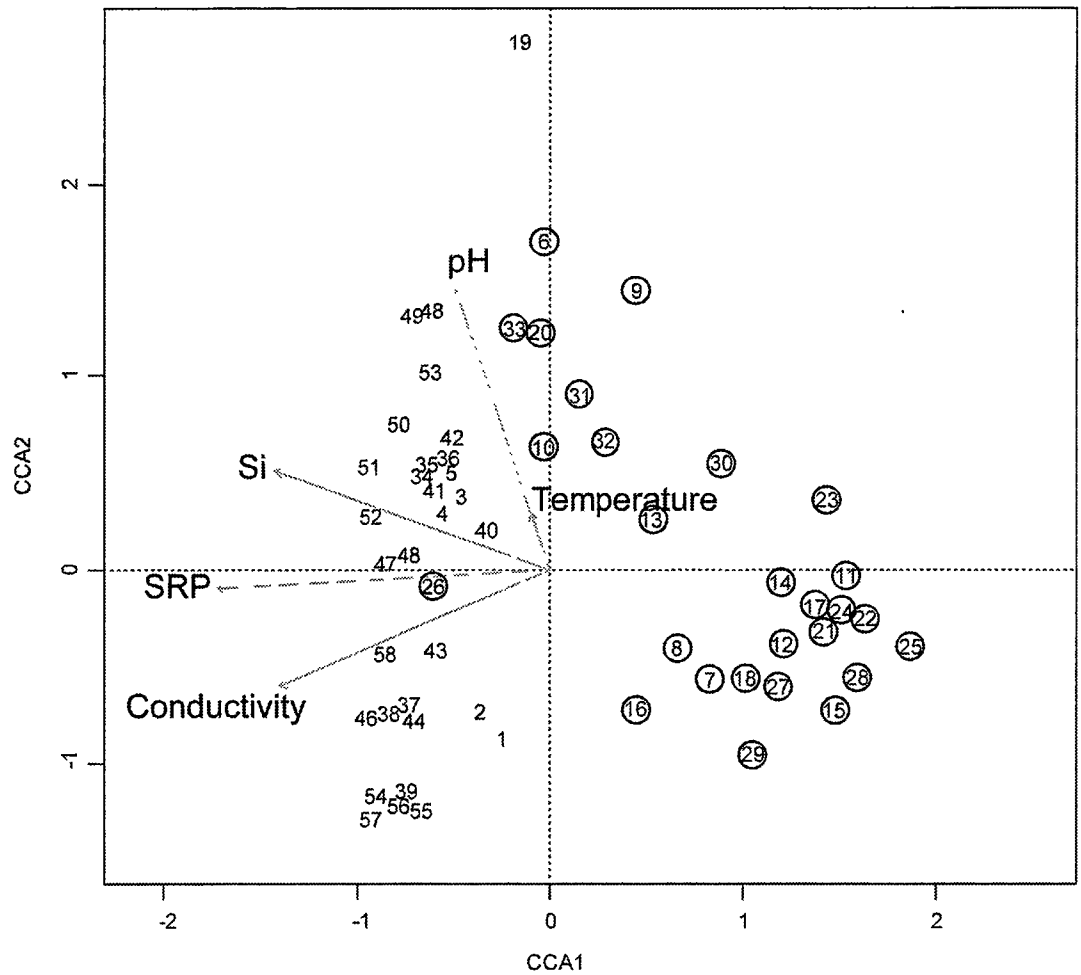


Figure 5.9: Canonical Correspondence Analysis of the Macquarie Island dataset with forward selected variables. Sites displayed. Inland sites are circled. Note: Si = silicate, SRP = soluble reactive phosphate. See Table 5.1 for site locations.

Table 5.7: Variance partitioning results. Note: SRP = soluble reactive phosphate, ∑ = sum.

Environmental variable	Covariable	∑ canonical eigenvalues	% variance explained	% interaction	p value
Conductivity	none	0.423	8.3	0	<0.005
	SRP	0.147	2.9	5.4	0.01
	Silicate	0.271	5.3	3.0	0.005
	Temperature	0.422	8.3	0	<0.005
	pH	0.421	8.2	0.1	<0.005
	Total interaction			8.5	
SRP	none	0.529	10.3	0	<0.005
	Conductivity	0.251	4.9	5.4	<0.005
	Silicate	0.293	5.7	4.6	0.005
	Temperature	0.522	10.2	0.1	<0.005
	pH	0.519	10.2	0.1	<0.005
	Total interaction			10.2	
Silicate	none	0.380	7.4	0	<0.005
	Conductivity	0.227	4.4	3.0	<0.005
	SRP	0.143	2.8	4.6	0.005
	Temperature	0.374	7.3	0.1	<0.005
	pH	0.344	6.7	0.7	<0.005
	Total interaction			8.5	
Temperature	none	0.136	2.7	0	0.043
	Conductivity	0.135	2.6	0.1	0.023
	SRP	0.128	2.5	0.2	0.002
	Silicate	0.130	2.5	0.2	0.033
	pH	0.140	2.7	0	0.005
	Total interaction			0.5	
pH	none	0.206	4.0	0	<0.005
	Conductivity	0.205	4.0	0	<0.005
	SRP	0.196	3.8	0.2	<0.005
	Silicate	0.171	3.3	0.7	<0.005
	Temperature	0.210	4.1	0.1	<0.005
	Total interaction			1.0	

5.3.4 Species optima and tolerances

Simple weighted averaging (WA) was used to determine species optima and tolerances for conductivity, pH, silicate, SRP and temperature. Optima and tolerances for all species are outlined in Appendix 7. Table 5.8 lists the optima and tolerances for the most abundant taxa in the Macquarie Island dataset. Figures 5.10 to 5.14 illustrate the distribution and abundance of dominant diatom species along these environmental gradients.

There were clear transitions in the abundance and occurrence of most of these diatoms along the major environmental gradients:

- *Aulacoseira distans, Eunotia paludosa, Navicula* sp. 1 and Unknown sp. 1 were more abundant at sites with conductivities < 200 μS cm^{-1}, while *Planothidium delicatulum* and *Planothidium quadripunctatum* were more abundant at higher conductivity sites (i.e. > 1000 μS cm^{-1}, Figure 5.10).
- *Aulacoseira distans* was more abundant at acidic sites (i.e. pH < 6), while *Cocconeis pediculus* was more abundant at alkaline sites (i.e. pH > 8, Figure 5.11).
- *Eunotia paludosa, Stauroneis* sp. 1 and Unknown sp. 1 were more abundant at sites with silicate concentrations < 10 μg Si L^{-1}, while *Cocconeis pediculus, Fragilaria capucina* and *Planothidium delicatulum* were more abundant at sites with silicate concentrations > 500 μg Si L^{-1} (Figure 5.12).
- *Eunotia paludosa, Navicula* sp. 1, *Psammothidium abundans, Stauroneis* sp. 1, *Staurosira venter* and Unknown sp. 1 were more abundant at sites with SRP concentrations < 5 μg P L^{-1}, while *Cyclotella meneghiniana* and *Planothidium delicatulum* were more abundant at sites with SRP concentrations > 1000 μg P L^{-1} (Figure 5.13).
- *Staurosira venter, Planothidium quadripunctatum* and *Psammothidium abundans* were more abundant at sites with lower temperatures (i.e. < 6 °C), while *Cocconeis pediculus* and Unknown sp. 1 were more abundant at warmer sites (i.e. > 10 °C Figure 5.14).

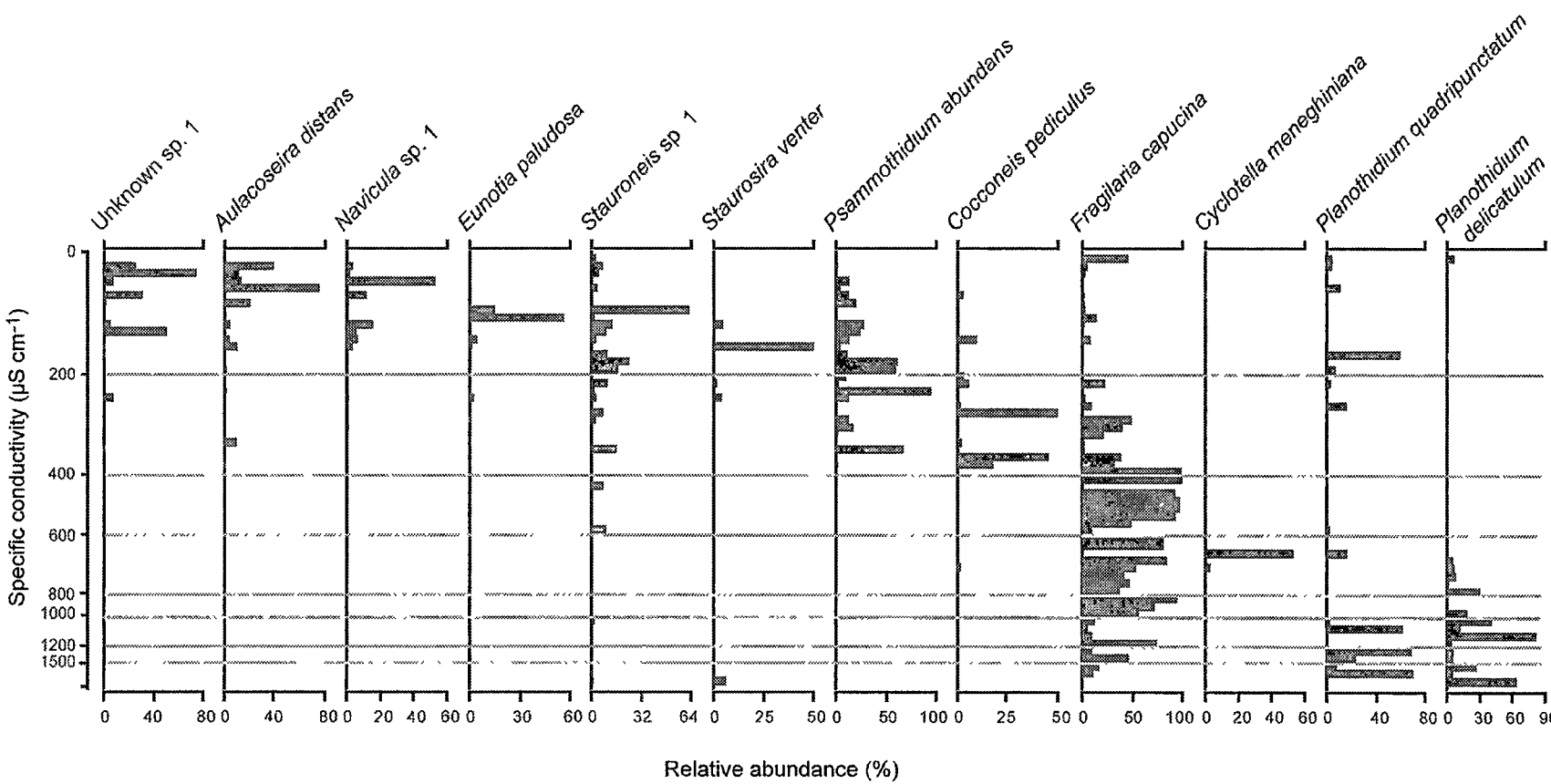


Figure 5.10: Dominant diatom species distribution along the conductivity gradient in the Macquarie Island dataset.

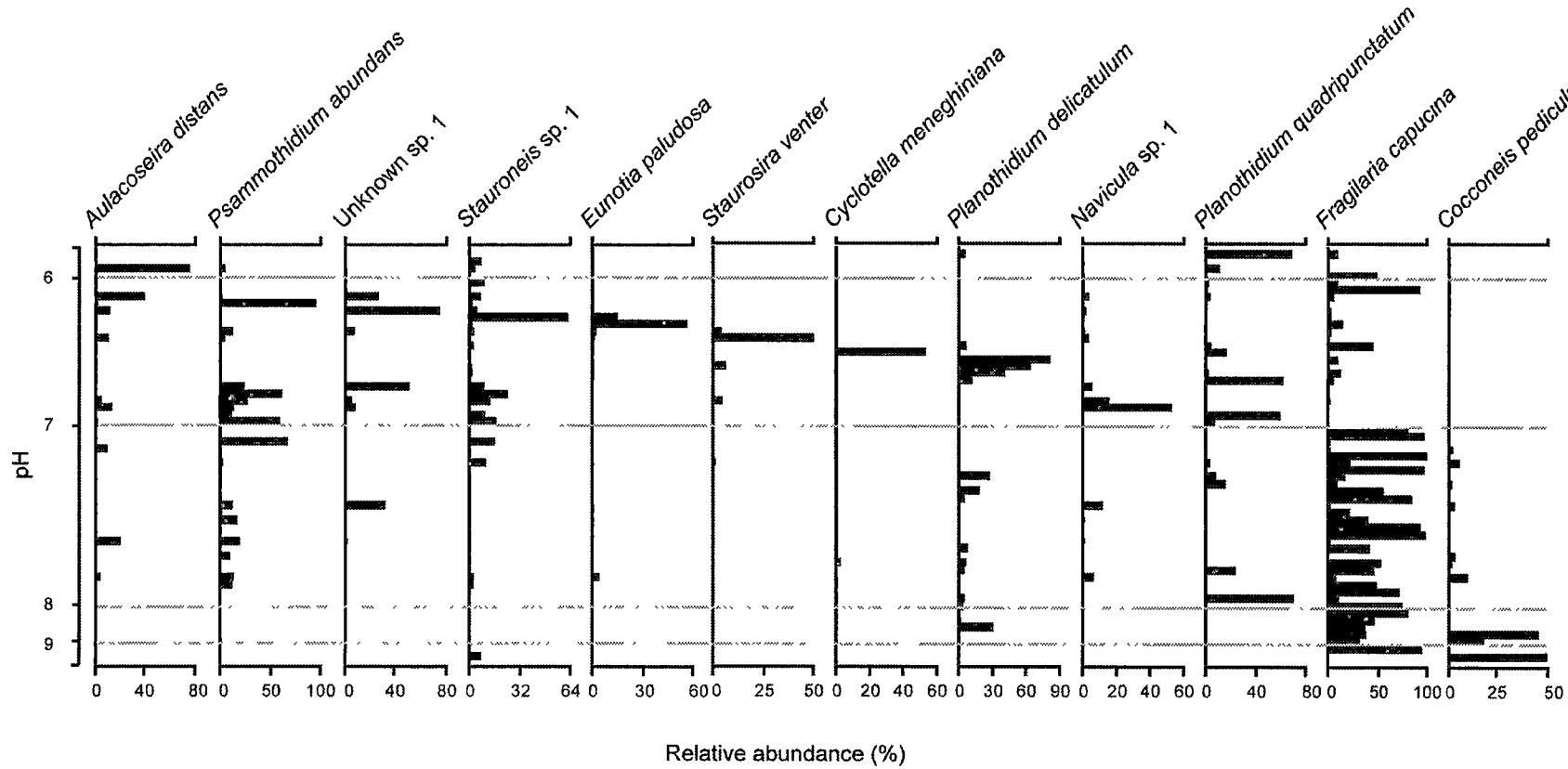


Figure 5.11: Dominant diatom species distribution along the pH gradient in the Macquarie Island dataset.

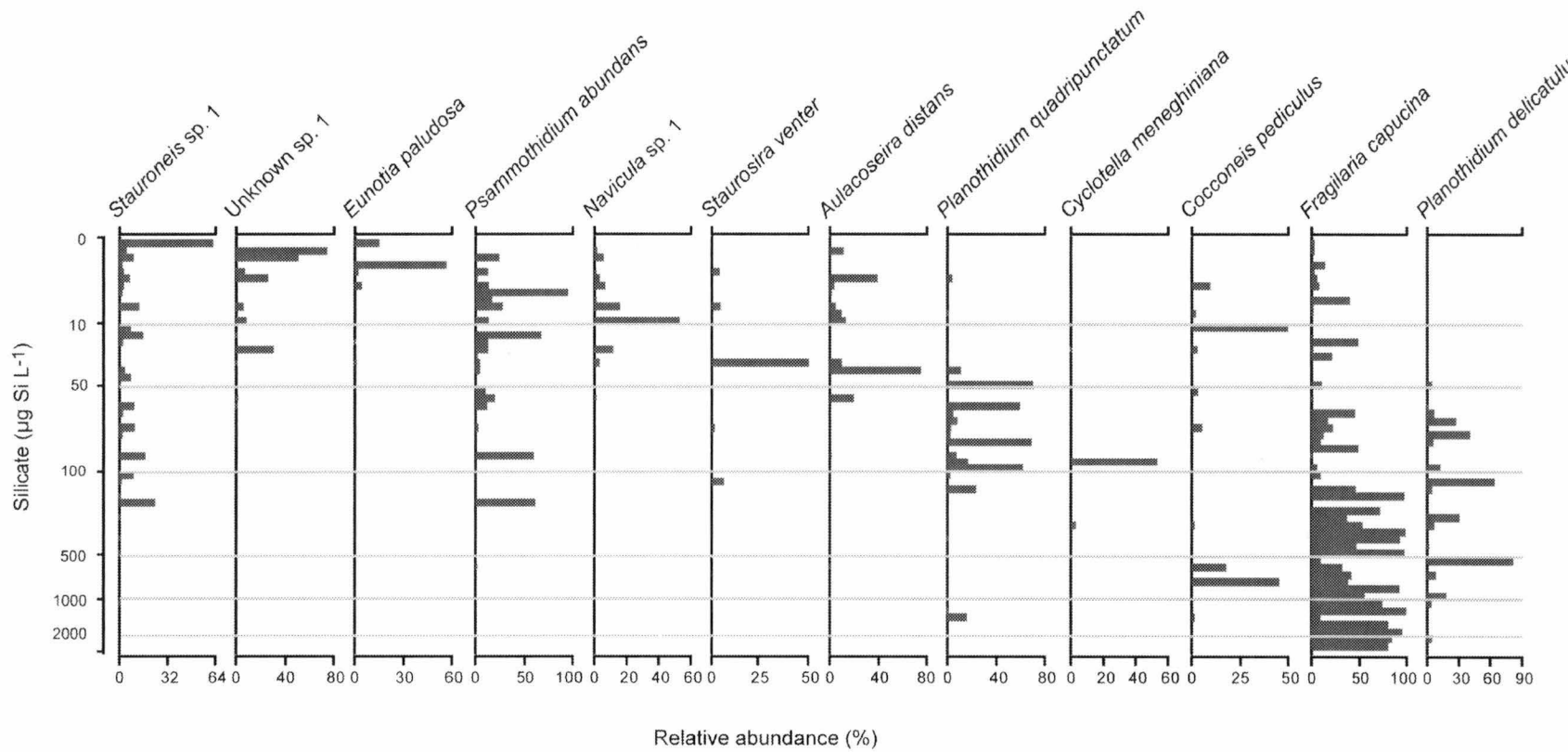


Figure 5.12: Dominant diatom species distribution along the silicate gradient in the Macquarie Island dataset.

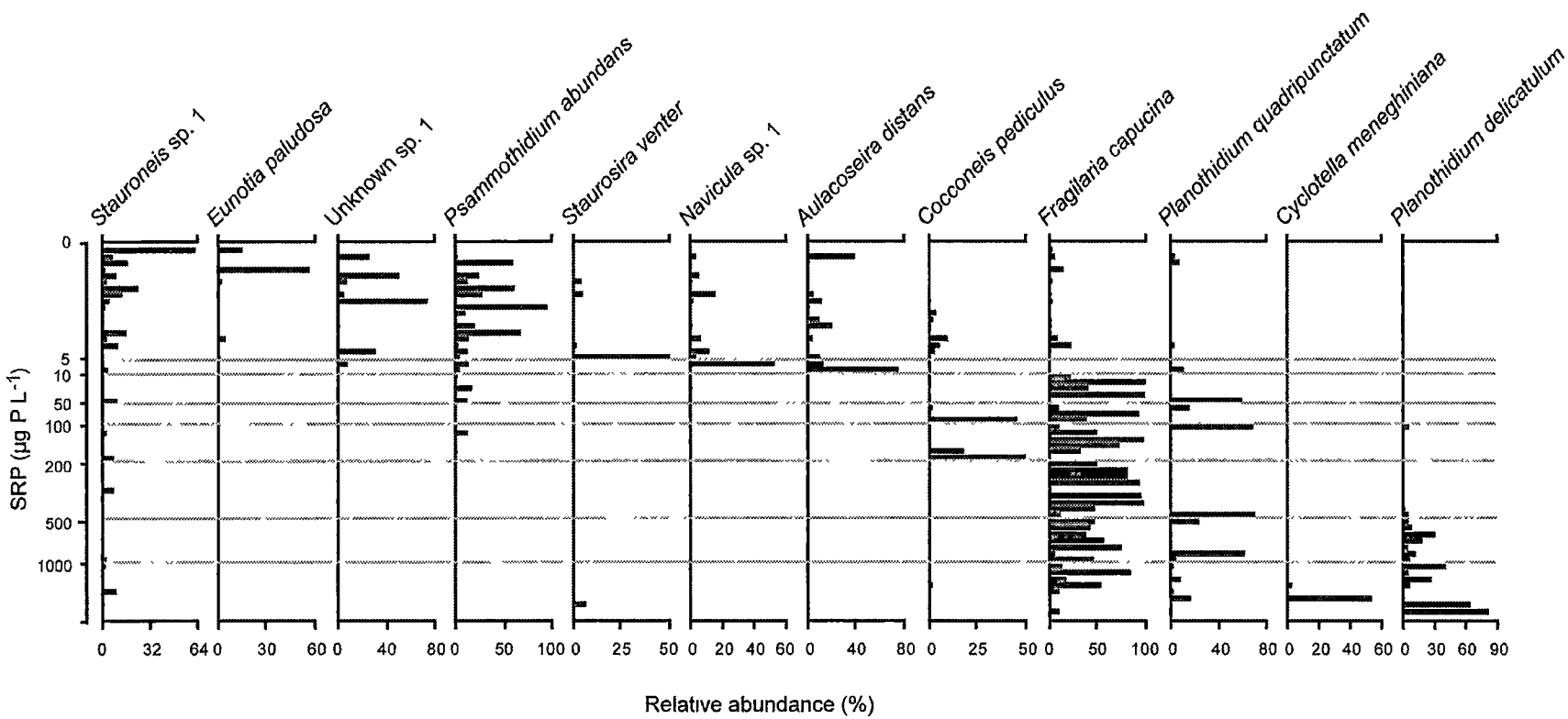


Figure 5.13: Dominant diatom species distribution along the soluble reactive phosphate (SRP) gradient in the Macquarie Island dataset.

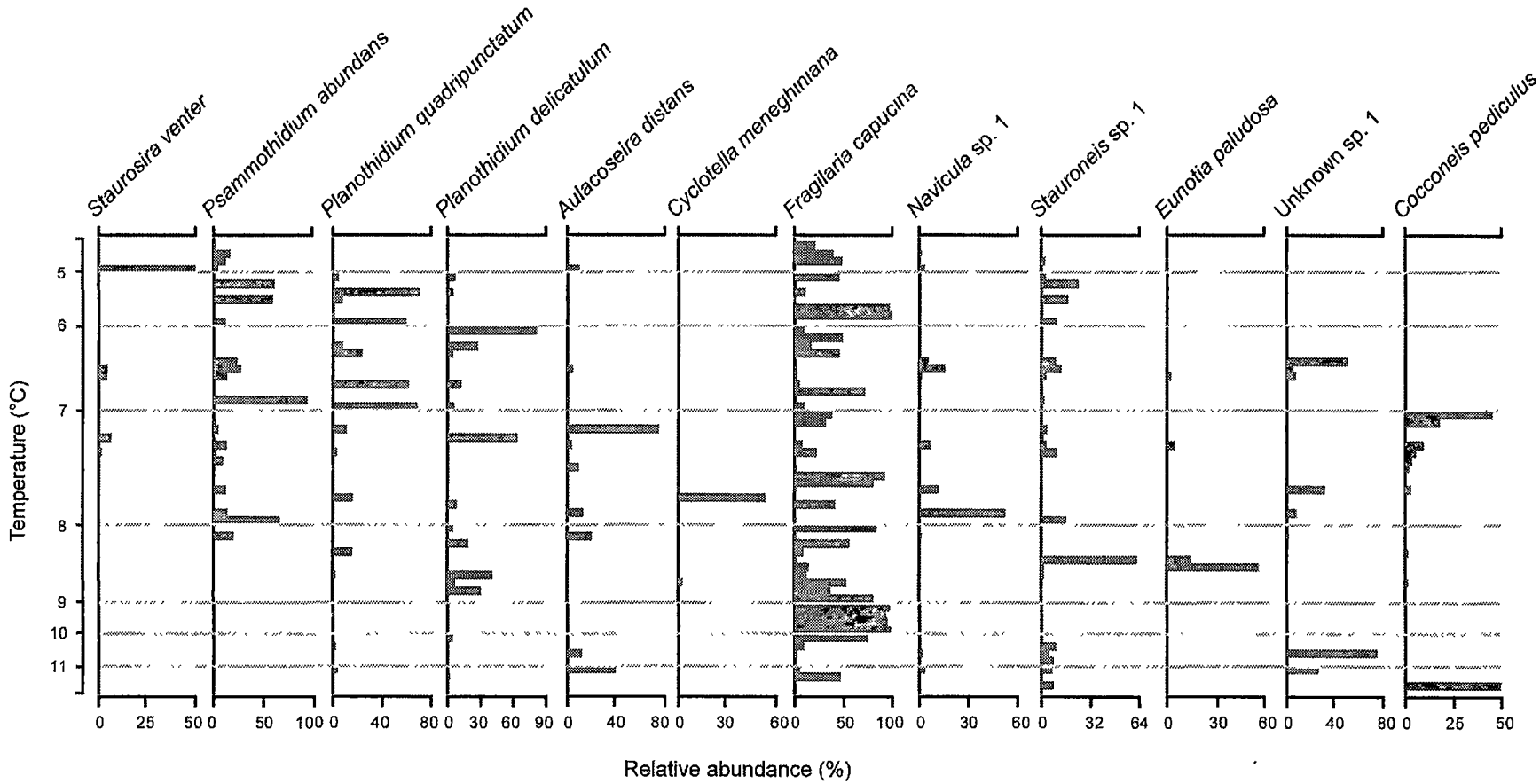


Figure 5.14: Dominant diatom species distribution along the temperature gradient in the dataset.

5.3.5 Diatom-based transfer functions

As pH, SRP, conductivity, silicate and temperature explained independent portions of the variance in the diatom data, transfer functions for these were developed. Both simple WA and weighted averaging partial least squares (WAPLS) were used to determine which model led to the best performing transfer function for each environmental variable (Table 5.8). Simple WA resulted in the best performing conductivity, pH, SRP and temperature transfer functions (Figures 5.15 to 5.18). WAPLS-2 components led to the best performing silicate transfer function (Figure 5.19).

The SRP transfer function had the best predictive ability ($r^2p = 0.80$), followed by conductivity ($r^2p = 0.66$) and silicate ($r^2p = 0.61$), while the pH and temperature transfer functions performed worst ($r^2p = 0.29$ and $r^2p = 0.23$ respectively).

Table 5.8: Transfer function results for conductivity, pH, silicate, soluble reactive phosphate (SRP) and temperature. All models are jackknifed. Note: phosphate, silicate and temperature were $\log_{(x+1)}$ transformed, r^2p = predicted r^2, RMSE = root mean squared error, RMSEp = root mean squared error of prediction, WA_{cla} = weighted averaging with classical deshrinking, WA_{inv} = weighted averaging with inverse deshrinking, WAPLS-2 = weighted averaging partial least squares (two components).

Variable	r^2	r^2p	RMSE	RMSEp	Model
Conductivity	0.82	0.66	0.11	0.14	WA_{cla}
pH	0.70	0.29	0.44	0.68	WA_{inv}
Silicate	0.91	0.61	0.25	0.53	WAPLS-2
SRP	0.90	0.80	0.40	0.50	WA_{cla}
Temperature	0.68	0.23	0.05	0.08	WA_{inv}

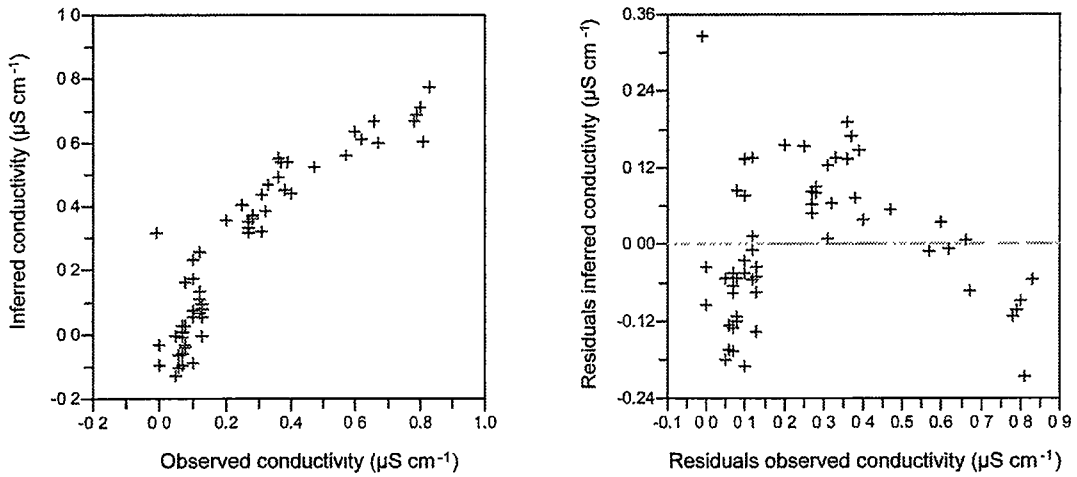


Figure 5.15: Conductivity transfer function performance of the Macquarie Island dataset.

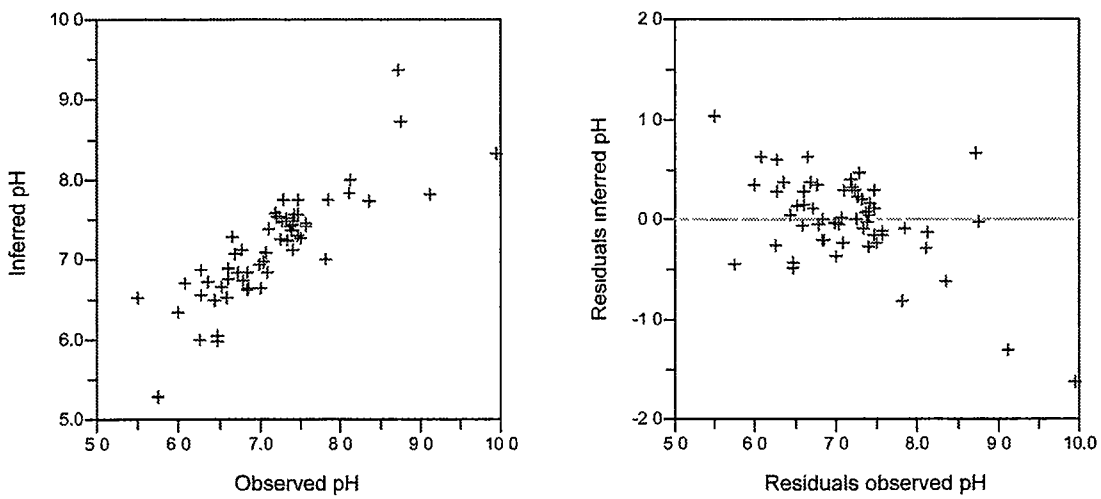


Figure 5.16: pH transfer function performance of the Macquarie Island dataset.

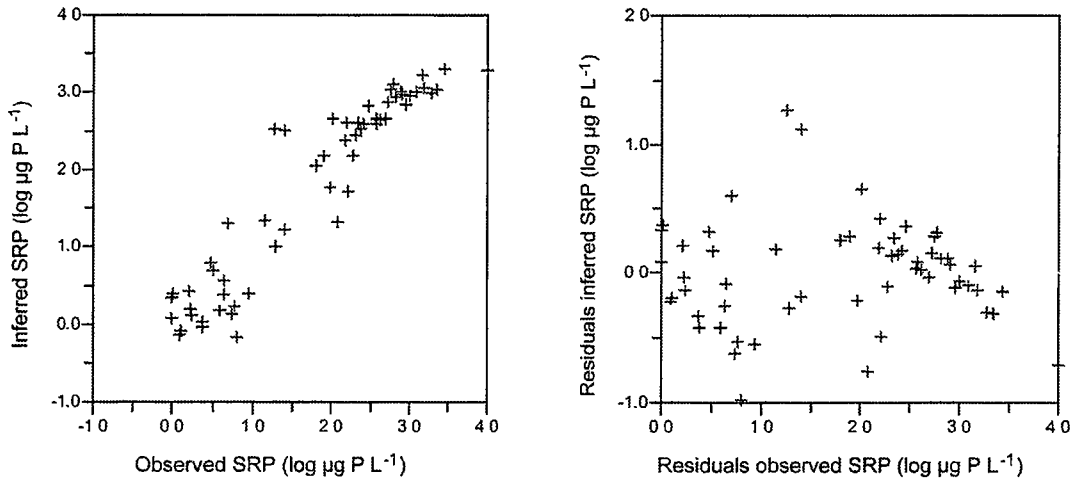


Figure 5.17: Soluble reactive phosphate (SRP) transfer function performance of the Macquarie Island dataset.

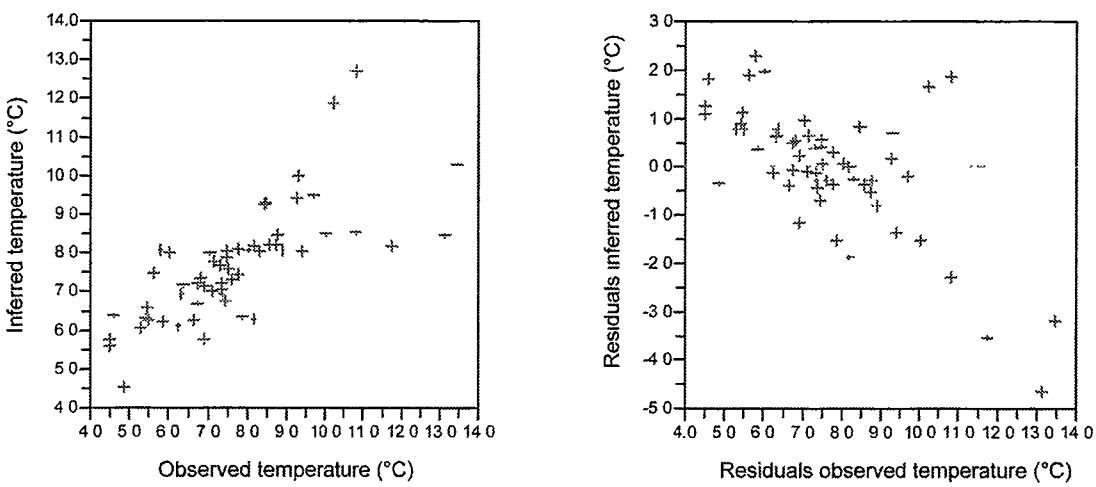


Figure 5.18: Temperature transfer function performance of the Macquarie Island dataset.

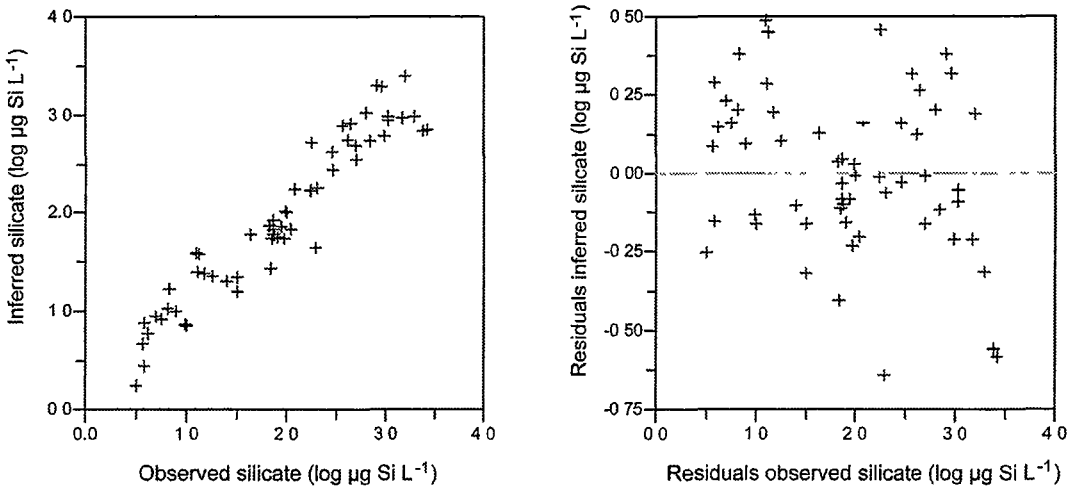


Figure 5.19: Silicate transfer function performance of the Macquarie Island dataset.

5.4 Discussion

The aims of this Chapter were to determine major environmental gradients occurring in Macquarie Island lakes and major environmental gradients influencing diatom species; provide baseline, species-level data on the composition and distribution of surface sediment diatom communities and their ecological preferences, and develop transfer functions based on these environmental variables.

5.4.1 Limnology

The lakes analysed in this study were all freshwater. There was a wide range of nutrient concentrations ranging from mostly oligotrophic lakes on the plateau to eutrophic lakes on the coastal terrace. There were similar wide ranges in dissolved oxygen, pH, temperature and turbidity. Eutrophic lakes and ponds commonly occur along the coastlines of sub-Antarctic and maritime Antarctic islands (e.g. Jones *et al.* 1993, Van de Vijver & Beyens 1999), reaching greater than 1000 µg P L^{-1} and 1000 µg N L^{-1} (e.g. Île de la Possession, Van de Vijver & Beyens 1999, and this study, Table 5.1). Macquarie Island is far removed from major anthropogenic atmospheric inputs of nitrogen and other nutrients. However, substantial nutrient inputs occur due to seals, penguins and other seabirds. These

animals deposit large quantities of excrement onto the island. For example, soils near nesting animals have been found to have nitrogen concentrations 4-8 times higher than soils sampled away from marine mammals and avian influences, while nitrogen concentrations in *Poa annua* near animal influences are equivalent to fertilized crop plants (Erskine *et al.* 1998). In addition, the range of ^{15}N found in plants on Macquarie Island is three times greater than in the sub-Arctic and Arctic plants (i.e. 30 ‰ compared to 10 ‰; Erskine *et al.* 1998) and is highly correlated to proximity to animal influences. The highest SRP and nitrate/nitrite values recorded in this study were near seal or penguin colonies (e.g. most coastal sites and inland sites 6, 19 and 20, which were near royal penguin rookeries and site 26, which was near a king penguin rookery).

PCA of the environmental data shows that in addition to the influence of conductivity detected by Buckney and Tyler (1974), the lakes are also organised along gradients of nutrients and turbidity, and to a lesser extent, pH and dissolved oxygen (Figure 5.6). PCA with geographical and physical factors plotted as passive variables demonstrates the influence of distance from the west coast and the importance of the prevailing weather characteristics on nutrients, conductivity, temperature and turbidity (Figures 5.20-5.21). With increasing distance from the west coast, these environmental variables decrease. All of the passive variables were highly correlated with each other, which can be explained by the westerly weather patterns that dominate the climate of Macquarie Island and the absence of lakes on the eastern coastal terrace.

5.4.2 Ecological preferences of diatom communities on Macquarie Island

The frequency distribution of selected taxa in the dataset provides examples of how individual species abundances respond to selected environmental variables (Figure 5.22). This, together with clear transitions in species abundance and occurrence (Figures 5.10-5.14), highlights the large limnological gradients in the lakes on Macquarie Island and allows potential indicator species for different environmental conditions on Macquarie Island to be identified.

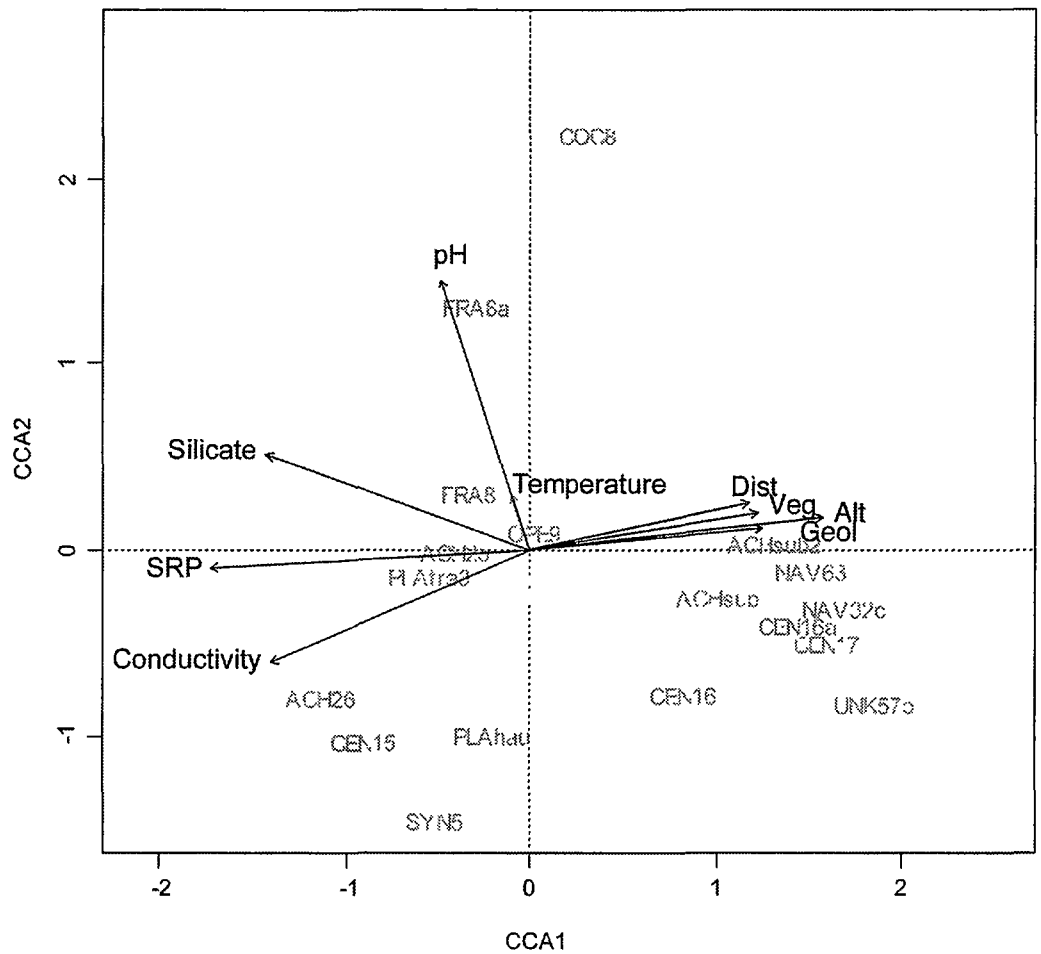


Figure 5.20: Canonical Correspondence Analysis with passive geographical variables added, illustrating the influence of distance from the west coast and importance of the prevailing weather characteristics on conductivity, nutrients (soluble reactive phosphate, SRP), pH and temperature gradients in Macquarie Island lakes and ponds. Dominant species (i.e. species occurring with a maximum relative abundance ≥ 20% and occurring in ≥ 5 samples) displayed. Note: Alt = altitude, Dist = distance from west coast, Geol = geology, Veg = surrounding vegetation cover. See Appendix 5 for a list of species names.

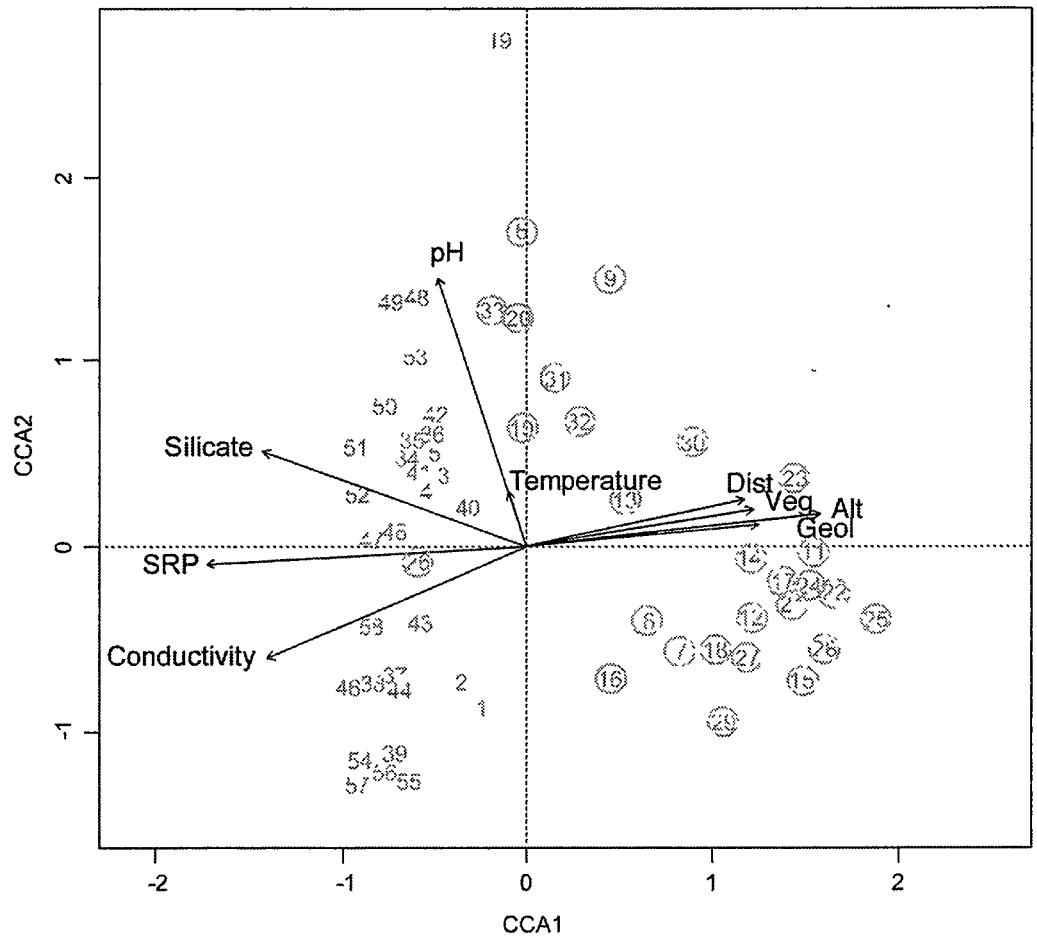


Figure 5.21: Canonical Correspondence Analysis with passive geographical variables added, illustrating the influence of distance from the west coast and importance of the prevailing weather characteristics on conductivity, nutrients (soluble reactive phosphate, SRP), pH and temperature gradients in Macquarie Island lakes and ponds. Sites displayed with inland sites circled. Note: Alt = altitude, Dist = distance from west coast, Geol = geology, Veg = surrounding vegetation cover. See Table 5.1 for site locations.

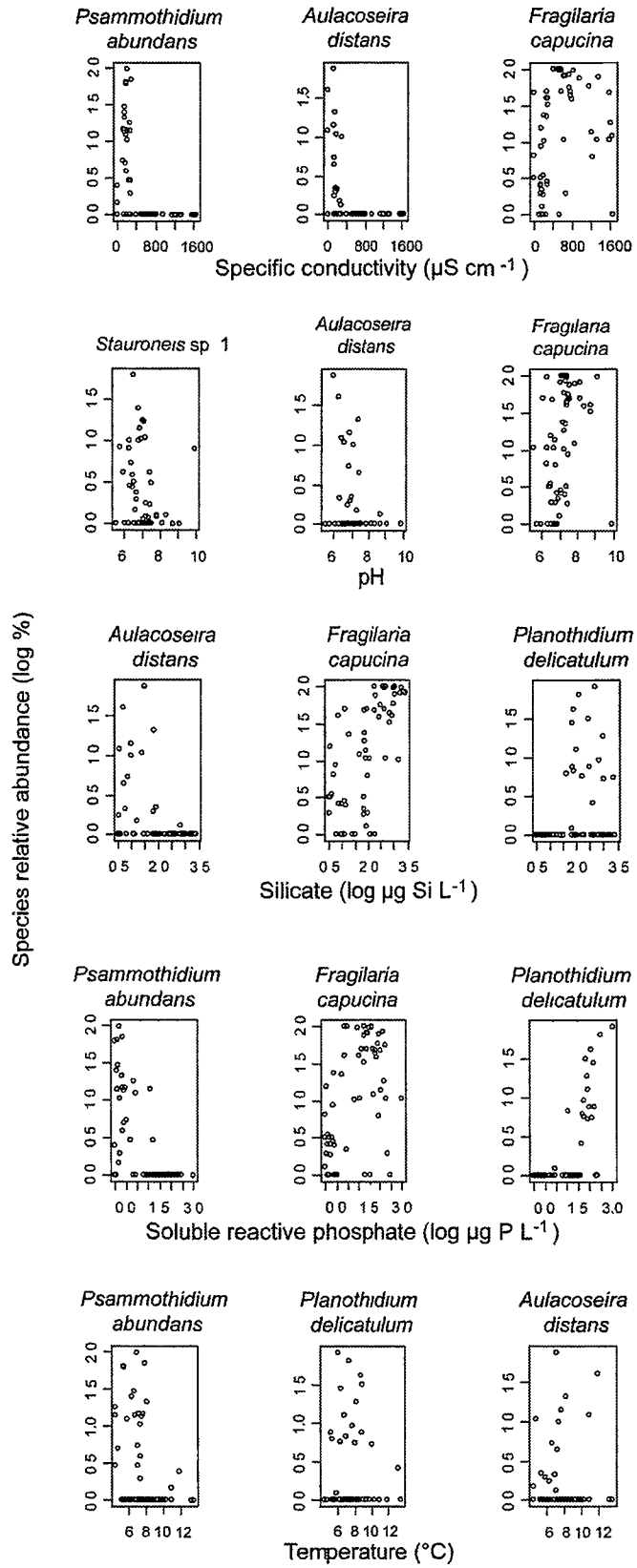


Figure 5.22: Examples of dominant diatom species abundance in the Macquarie Island dataset in relation to the different environmental variables.

Diatom taxa characteristic of higher nutrient concentrations and conductivity include *Planothidium delicatulum* and *Cyclotella meneghiniana* (Figure 5.7). These are both cosmopolitan species and *Planothidium delicatulum* has previously been found on the Antarctic continent and Macquarie, South Orkney and South Shetland Islands and Îles Kerguelen (see Van de Vijver *et al.* 2002a). *Cyclotella meneghiniana* is common in eutrophic systems (Weckström & Juggins 2006) and has previously been found on Île de la Possession by Van de Vijver & Beyens (1999) when nutrient enrichment was sufficient. In the present study, *Cyclotella meneghiniana* was also most abundant at a coastal site located near a penguin colony (site 56) with high SRP and nitrate/nitrite (i.e. SRP > 2000 $\mu g\ P\ L^{-1}$, > 1900 $\mu g\ N\ L^{-1}$, Table 5.1). Planktonic species are generally absent from Antarctic diatom assemblages (Jones *et al.* 1993, Jones 1996), apart from some brackish-marine lakes in the Vestfold Hills, east Antarctica, where the diatom flora includes planktonic marine and sea ice diatoms (Verleyen *et al.* 2003). The general absence of planktonic diatom taxa in sub-Antarctic lakes contrasts with lakes in more temperate regions in the Southern Hemisphere, where planktonic diatoms often dominate (Van de Vijver & Beyens 1999).

Aulacoseira distans, like *Cyclotella meneghiniana*, is a tychoplanktonic species that featured widely in this dataset, but only in inland lakes. It has also been identified on King George Island, South Georgia, Kerguelen and Crozet Islands, and Île de la Possession (Van de Vijver *et al.* 2002a). This is a heavily silicified species that needs water turbulence and/or high water levels to maintain suspension in the water column. A high or increasing abundance of *Aulacoseira distans* in diatom assemblages may indicate increased mixing intensity or lake level (Köster *et al.* 2004).

Psammothidium abundans is a benthic diatom associated with prostrate microbial mats (Verleyen *et al.* 2003). Diatom communities characteristic of low nutrient and conductivity conditions on Macquarie Island include *Eunotia paludosa*, which is characteristic of freshwaters elsewhere and is acidophilous, and *Navicula* sp. 1 and Unknown sp. 1, which have both been found elsewhere in the sub-Antarctic, but have yet to be fully identified and described (Bart Van de Vijver *pers commun.* August 2007).

5.4.3 Evaluation of transfer functions

Based on the dataset, statistically robust transfer functions for SRP and conductivity were developed (Table 5.9). A well performing silicate transfer function was developed using WAPLS-2 components, however, due to the large amount of interaction between silicate and SRP and silicate and conductivity (i.e. 4.6% and 3.0% respectively), it would be difficult to distinguish a difference due to silicate alone. Therefore, use of this transfer function is not recommended.

The distribution of species occurrence in the dataset illustrates the clear transitions between species and changes in the concentration of each variable (Figure 5.10-5.14, 5.21). The performances of the SRP and conductivity transfer functions are comparable to previous studies (see Chapter 3, Table 3.17).

The transfer functions for pH and temperature had relatively poor predictive performance (Table 5.9). This is surprising as there is a long, relatively well-populated pH gradient in the dataset. However, the diatoms seem to be pre-adapted to wide pH gradients and do not show the limited tolerances that are necessary to develop strong transfer functions. This is illustrated in the plot of diatom species occurrences along the pH gradient in the dataset: while some species only occur at low and high pH, most occur throughout the pH gradient (Figure 5.9). Similarly, the diatom-temperature transfer function had relatively poor predictive ability, due likely to the uneven distribution of lakes along the temperature gradient, with generally higher temperatures recorded in lakes located on the coastal terrace and lower temperatures recorded in lakes on the plateau. The influence of temperature is confounded by the influence of distance from the west coast and the importance of this in controlling the supply of nutrients and ions (conductivity) to the lakes. As indicated by a plot of the occurrence of dominant species along the temperature gradient, the diatoms do not show as clear transitions along this gradient as they do with other environmental variables, although some species appear to be more abundant at either end of the temperature gradient (Figure 5.13). However, temperature can still be an important driving factor and diatom-temperature transfer functions have previously been developed for high latitude locations (Pienitz *et al.* 1995, Joynt & Wolfe 2001, Wolfe 2003, Gremmen *et al.* 2007). Further sampling to increase the number of samples in this dataset over a more evenly distributed altitudinal

gradient may improve the performance of the diatom-temperature transfer function.

5.5 Conclusions

This study has provided an overview of water quality and environmental gradients in Macquarie Island lakes, the composition of diatom assemblages and major environmental variables determining species distribution, in particular the importance of animals supplying nutrients to the lakes. Conductivity, pH, silicate, SRP and temperature significantly influenced diatom species occurrence and there are strong nutrient and conductivity gradients across the island from west to east. The SRP and conductivity transfer functions performed well, while the amount of interaction between silicate and the other variables meant application of a silicate transfer function is not appropriate. The pH and temperature transfer functions performed relatively poorly, but may still be used to qualitatively investigate trends.

The following Chapter endeavours to apply the phosphate, salinity and temperature transfer functions to a sediment core to reconstruct past environmental conditions on Macquarie Island.

Assessing Holocene climate variability and the impact of feral animals on World Heritage sub-Antarctic Macquarie Island

6.1 Introduction

Climate change, introduced species and habitat fragmentation are considered to be major threats to global biodiversity (Anderson *et al.* 2006, Hilton *et al.* 2006). Despite the sensitivity of sub-Antarctic ecosystems, there is little published information on past climate variability, recent climate change or the implications of predicted climate change on sub-Antarctic ecosystems (Pendlebury & Barnes-Keoghan 2007). The sub-Antarctic and Antarctic are unique because they have never had an indigenous human population or a long history of human occupation or impacts (Convey 2007). However, the sub-Antarctic in particular, has experienced extensive environmental degradation as a result of human activities during the last two centuries.

Sparse records make generalisations about past sub-Antarctic climates and climate variability difficult. However, evidence from sub-Antarctic islands south of New Zealand (Auckland and Campbell Islands), South America and South Georgia (Figure 6.1) suggests variable climatic conditions throughout the Holocene (i.e. since 11500 years BP) ranging from relatively wet and windy conditions during the early Holocene (i.e. until c. 4000 years BP, McGlone *et al.* 2000, Lamy *et al.* 2001, Van der Putten *et al.* 2004), while the late Holocene climate (i.e. since c. 4000 years BP) was generally characterised by drier and warmer conditions (Lamy *et al.* 2001, McGlone 2002, Bentley *et al.* 2008). More recently, many meteorological observations in the sub-Antarctic region indicate rising temperatures since the mid 20th century (e.g. Tweedie & Bergstrom 2000, McGlone *et al.* 2007). However, the extent of change is not uniform (Scott & Kirkpatrick 2007) and a lack of data means accurate regional generalisations of climate change are difficult.

In addition, human contact since the early 19th century has led to the introduction of over 200 non-indigenous species (Frenot *et al.* 2005). These have often out-competed the indigenous flora and fauna and in some cases led to the latter's extinction. This is important as the total landmass of the sub-Antarctic is highly limited and the species are often globally restricted in their distribution.

Damage to these islands therefore presents an important threat to regional and global biodiversity (Convey 2007).

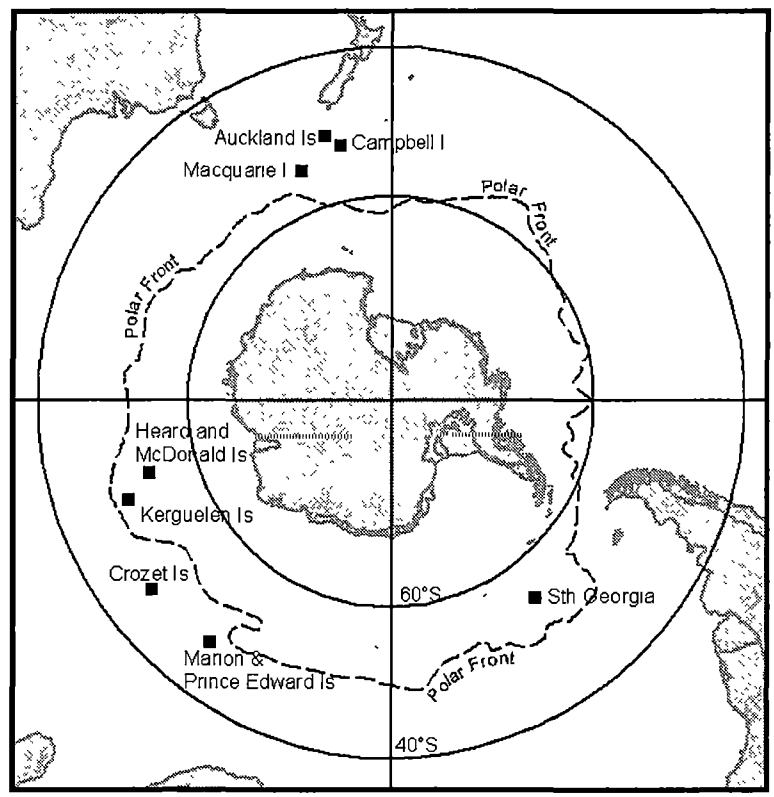


Figure 6.1: Location of sub-Antarctic islands. The location of the Polar Front is also marked (obtained from http://data.aad.gov.au/aadc/mapcat/display_map.cfm?map_id=13137).

Humans first discovered Macquarie Island in 1810 and activities were focused on exploiting the abundant seal and penguin populations, leading to their near-extinction towards the end of the 19th century (Townrow 1988). During this time a number of non-indigenous species were introduced (Table 6.1). Of particular importance were feral animals including cats, mice, rabbits, rats and weka whose expanding populations have had extensive effects on the fragile environment of Macquarie Island.

Dogs and cats were introduced as pets by sealers in the early 1800s, which led to serious destruction of the native flora and fauna (Mawson 1943). Dogs initially roamed the island, but there is no documentation of their presence after 1820 (Law & Burstall 1956). Cats soon became widespread (Taylor 1955) and led to the extinction of the Macquarie Island ground parakeet (*Cyanoramphus erythrotis* Wagner 1832), which was abundant when humans first arrived and still

existed in considerable numbers in 1880. The last report of a ground parakeet was in 1890 and they were extinct by 1894 (Mawson 1943, Taylor 1955).

Table 6.1: History of animal introductions to Macquarie Island.

Animal	Year	Current status	Reference
Cats	c. 1810	Eradicated by 2000	Taylor 1955, PWS 2007
Dogs	c. 1810	Not present after 1820	Taylor 1955, PWS 2007
Weka	1880	Eradicated by 1989	PWS 2007
Rabbits	1878	Feral	Scott 1988
Rats/mice	by 1894	Feral	Mawson 1943
Ducks and hens	1915	Not present	Law & Burstall 1956
Sheep	1915 and 1947	Not present	Taylor 1955, Law & Burstall 1956
Horses	1917	Not present	Law & Burstall 1956
Goats	1947	Not present	Law & Burstall 1956
Cows and pigs	1953	Not present	Law & Burstall 1956

Of those animals that developed feral populations, cats and weka have now been eradicated (the eradication program began in the 1970s and was completed in 2000 and 1989 respectively; PWS 2007). However, the greatest current threat facing Macquarie Island is the impact of the remaining introduced vertebrate species (i.e. rabbits, rats and mice), particularly the rapidly expanding rabbit population, which has occurred as a response to the removal of cats, reduced effectiveness of control measures and successively warmer winters (PWS 2007). As a consequence of increased burrowing and grazing pressure, large areas of vegetation have been destroyed, in particular extensive losses of tall tussock (*Poa foliosa* (Hook. F.) Hook. F.) and megaherbs (*Stilbocarpa polaris* (Homb. & Jacq.) Gray. and *Pleurophyllum hookeri*), which has caused substantial slope instability, erosion, increased occurrence and extent of landslips and loss of habitat (Scott *et al.* 2007, see Chapter 5, Figure 5.4). An extensive pest eradication program is currently being planned (PWS 2007). The key measures of its success will not only be the removal of all rabbits, rats and mice, but the subsequent response of the island's flora and fauna, including the establishment of healthy vegetation throughout the island and the extent to which the island's ecosystems are able to return to pre-impact conditions; in particular, the

stabilisation of albatross breeding slopes and the reestablishment of burrow nesting seabird populations on the island (Springer 2008).

Successful restoration and rehabilitation therefore requires an understanding of pre-impact conditions and the role of natural climate variability. This is important for assessing and predicting the implications of future global warming. Palaeoecological studies provide the only method for deriving this information and have previously been used to assess climate change, feral animal impacts, ecosystem responses and past animal populations on sub-Antarctic and maritime Antarctic islands (e.g. Hodgson & Johnston 1997, Hodgson *et al.* 1998b), the Antarctic peninsula (Zale *et al.* 1994) and continental Antarctica (e.g. Sun *et al.* 2000). To date, no such study has previously been undertaken on Macquarie Island.

6.2 Aims

The overall Aim of this Chapter is to document Holocene climate variability and ecosystems on Macquarie Island and assess the impact of feral animals.

The specific Aims are to:

1. Apply the phosphate, conductivity and temperature transfer functions developed in Chapter 5 to a sediment core from Emerald Lake to:
    (a) determine a Holocene climate record for Macquarie Island;
    (b) identify baseline conditions prior to human arrival on the island; and
    (c) document the rate and impact of the introduction of feral animals and determine their ecosystem impacts.
2. Use additional lake sediment proxies (i.e. analyses of particle size and total sedimentary carbon, nitrogen and sulphur contents) to provide further evidence of ecosystem changes.
3. Discuss climate variability during the Holocene, the ecological impacts of introducing feral animals and the implications for the future management and conservation of Macquarie Island.

6.3 Site description

Emerald Lake (54°40'22''S, 158°52'14''E) is a small, shallow lake (maximum depth 1-1.5 m) located in the northwest of Macquarie Island at an altitude of 170 m above sea level, approximately half way up the slope between the coast and the plateau (Figure 6.2). It is located in a severely rabbit grazed area. The lake is ideally situated to record changes in climate as it is shallow with a small drainage basin and is directly influenced by the prevailing westerly winds.

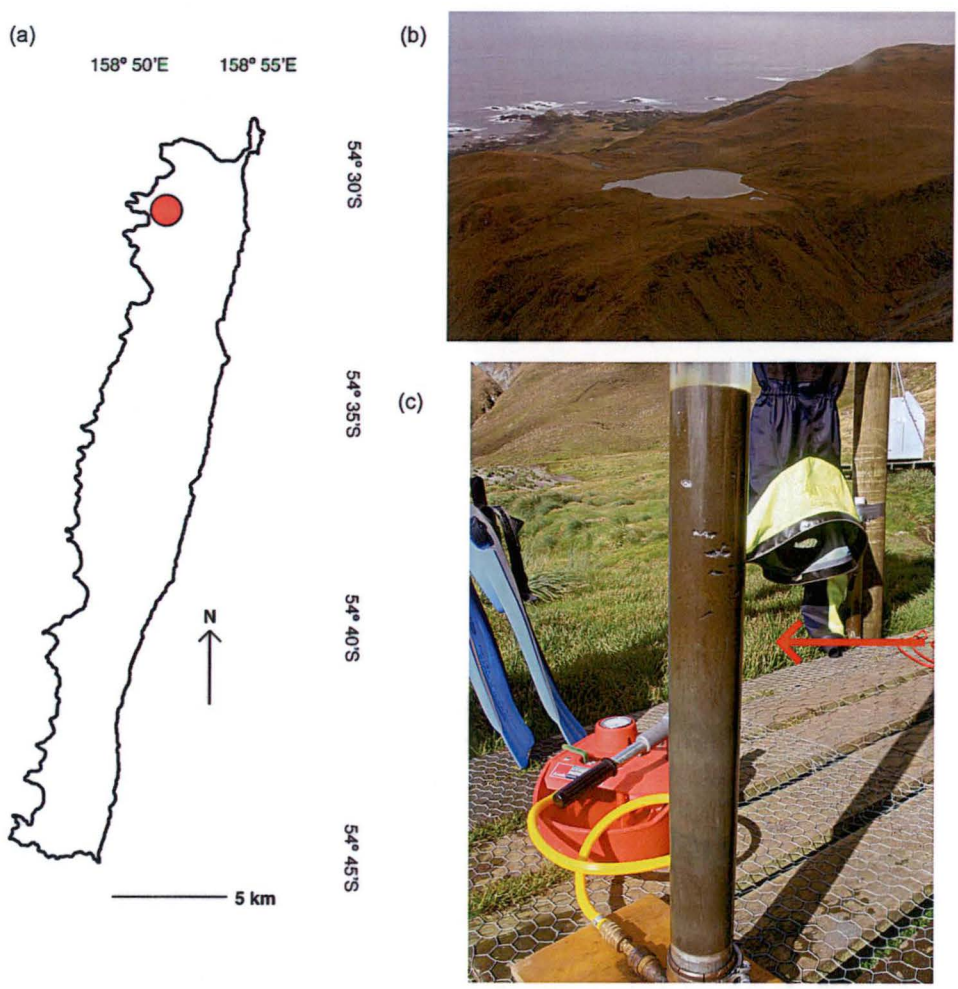


Figure 6.2: (a) Location of Emerald Lake on the northwest edge of the plateau; (b) aerial view of Emerald Lake showing its small, low relief catchment and exposure to the west coast; and (c) the sediment core collected from Emerald Lake and the sharp colour change at 22.0 cm depth (indicated by the red arrow).

6.4 Results

6.4.1 Core stratigraphy

As described in Chapter 2, a 50.5 cm sediment core was collected from a water depth of 1.0 m in Emerald Lake (Figure 6.2). Prior to sectioning, visual inspection of the core showed a large change in sediment colour and texture at 22.0 cm depth (Figure 6.3). Other colour changes were observed lower in the core with the lower 28.5 cm of the core having alternating grey and brown/red horizons (as illustrated in Figure 3). The very bottom 2.0 cm of the core was composed of brown sediments (Figure 6.3). Sediment inorganic composition was principally coarse-grained material consisting of silt (~ 50 %, > 63 μm) and mud (~ 40 %, 2-63 μm), with clay (< 2 μm) particles contributing < 7% throughout the core. Two peaks in mud occurred (reaching > 80 %) at 22.0 and 18.0 cm (Figure 6.3).

Below 18.0 cm sediment depth, total sedimentary carbon, nitrogen and sulphur were low. Total nitrogen was below detection limits, while total sedimentary carbon remained below 2.0 %. Total sulphur was only recorded at 40.0 cm and 30.0 cm (reaching 0.3 % and 0.2 % respectively). The total carbon to total nitrogen (C:N) mole ratio decreased from 50.0-20.0 cm (Figure 6.3).

From 18.0 cm to the surface of the core a dramatic change in the geochemistry occurred, with total nitrogen reaching a maximum of 0.5 % and total carbon a maximum of 6.1 % at 12.0 cm. Total sulphur peaked once (to 2.0 %) at 18.0 cm, before returning to low levels. The C:N mole ratio during this time was relatively high (> 18) and peaked at 10.0 cm and the surface of the core (Figure 6.3).

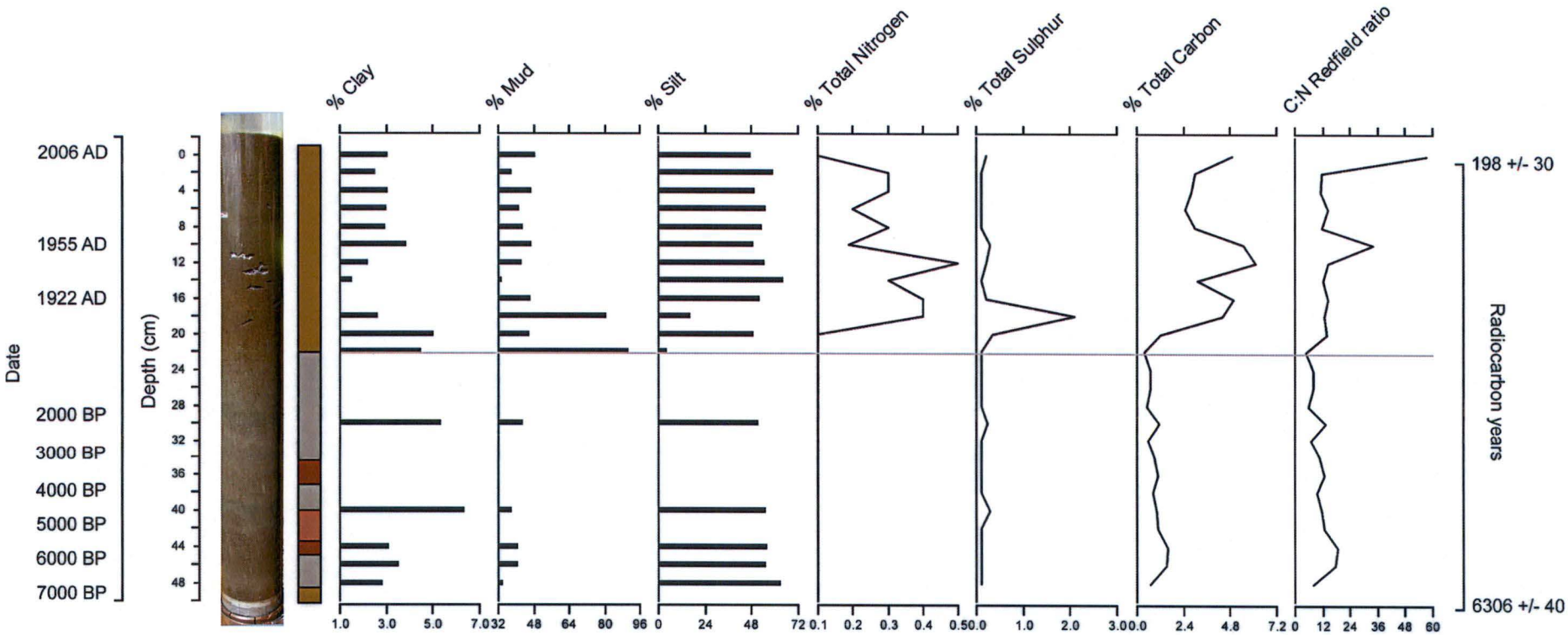


Figure 6.3: Grain size and total sedimentary nitrogen, sulphur and carbon contents in the Emerald Lake sediment core. The main stratigraphic horizon is marked as a grey line at 22.0 cm. Ages from 0-16 cm are based on ^{210}Pb dating (presented as years AD). Below this point ages are estimated based on linear interpolation between the end of ^{210}Pb dating and ^{14}C inferred age at the base of the core (50.5 cm, c. 7200 calibrated years BP). These are presented as years BP. The radiocarbon dates are also presented on the right hand side. Photo of Emerald Lake sediment core and sediment colour (■ = light brown, ■ = grey, ■ = brown/red, ■ = brown/red and grey) are also illustrated.

6.4.2 Core chronology

^{210}Pb and ^{14}C dating were used to develop a chronology for the sediment core. The ^{210}Pb profile exhibited exponential decay, little mixing and three zones of differing sedimentation rates (Figure 6.4). Below 20.0 cm, ^{210}Pb activities were low and constant and were not used in sedimentation rate calculations. Both the Constant Initial Concentration (CIC) and Constant Rate of Supply (CRS) models were used to determine a chronology for the core and gave similar results. The age of the sediment at 16.25 ± 0.25 cm was estimated at 83.7 ± 6.1 (CIC) to 92.9 ± 1.1 (CRS) years old. Due to significant catchment disturbance occurring during the 20th century, the CIC model was used in preference to provide a chronology for the upper 16.25 ± 0.25 cm of the sediment core (Figure 6.5). The three zones of sedimentation were: 0.16 cm yr^{-1} from 16.0-10.0 cm (c. 1906-1954 AD); 0.74 cm yr^{-1} from 10.0-6.0 cm (c. 1954-1960 AD); and 0.14 cm yr^{-1} from 6.0 cm to the surface (c. 1960-2006 AD).

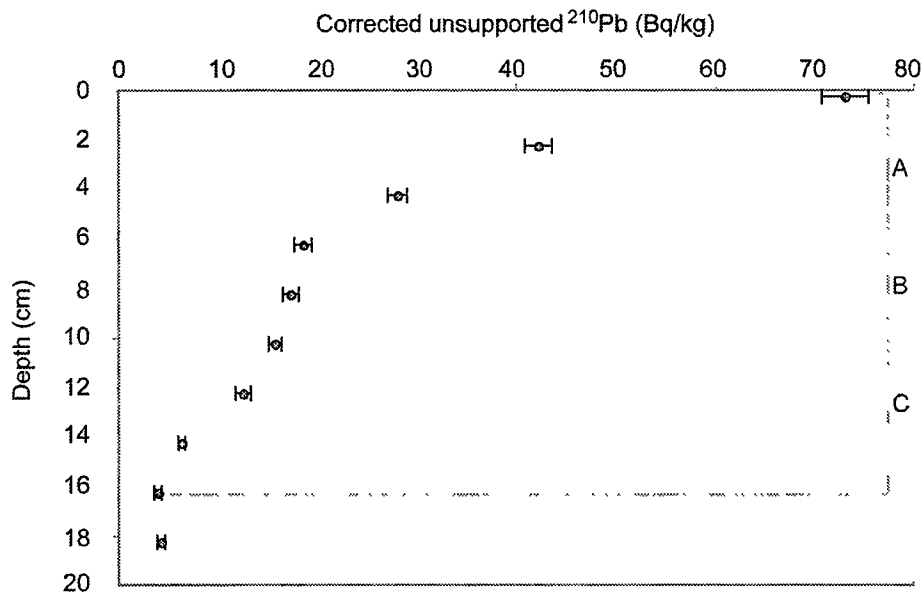


Figure 6.4: Corrected unsupported ^{210}Pb activity in the Emerald Lake sediment core. The different zones of sedimentation are labelled A (0-6 cm), B (6-10 cm) and C (10-16 cm). Samples reached background below 18 cm.

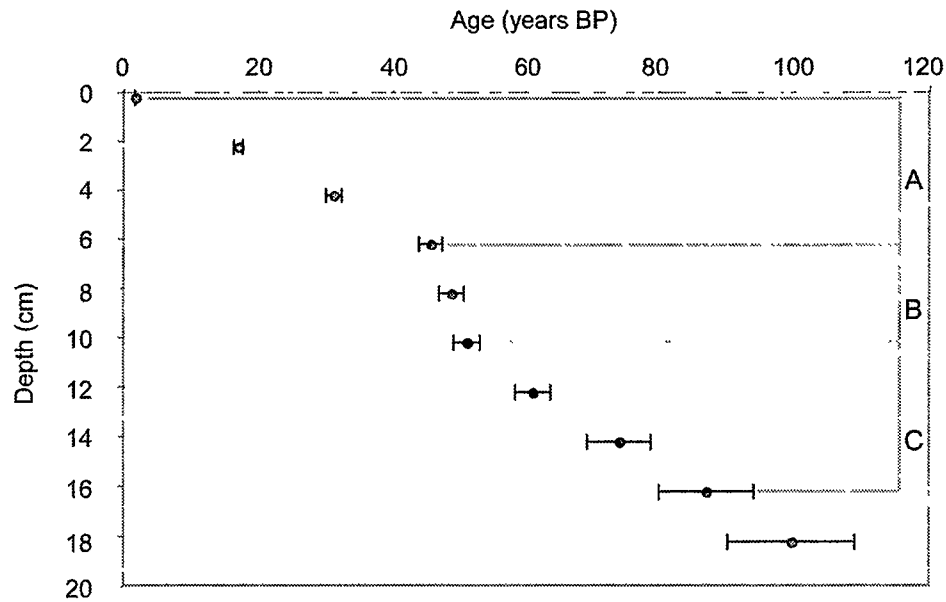


Figure 6.5: ^{210}Pb derived ages based on the Constant Initial Concentration (CIC) model and three zones of sedimentation for the Emerald Lake sediment core.

^{14}C dating of bulk sediments was used to establish the age at the base of the core. The base (50-50.5 cm) of the core was dated at 6306 ± 40 radiocarbon years BP (c. 7200 calibrated years BP). The surface was also dated and found to be 'modern' (198 ± 30 radiocarbon years BP). An additional sample was dated (22-22.5 cm), and reported an age of 2873 ± 20 radiocarbon years BP (c. 3000 calibrated years BP, Table 6.2).

Based on the visual stratigraphy, ^{210}Pb and geochemistry data, a period of more rapid sedimentation occurred from at least 16.0 cm and most likely from 22.5 cm to the surface as a result of substantially increased sediment inputs into the lake from the catchment, which is consistent with evidence for the onset of widespread slope instability in the catchment (Figure 6.6). Thus, the radiocarbon age at 22.0 cm is not in agreement with the ^{210}Pb age and is interpreted as a consequence of old carbon being incorporated into the lake sediment record from the rapid erosion of the catchment (Lowe & Walker 2000).

Table 6.2: ^{14}C results on bulk sediments from the Emerald Lake sediment core. Note: % modern means absolute per cent modern relative to the NBS oxalic acid standard C as defined by Stuiver & Polach (1977).

Depth cm	Radiocarbon age years BP	$\delta^{13}C$ ‰	% modern*	$\delta^{14}C$ ‰	Calibrated age years BP
0-1	198 ± 30	-24.4	96.9 ± 0.37	-31 ± 3.7	295-136 (73.0% of area) + 114-59 (13.8% of area) + 27-0 (8.3% of area)
22-22.5	2873 ± 20	-24.9	69.45 ± 0.16	-305.5 ± 1.6	3004-2955 (51.1% of area) + 3029-3012 (10.9% of area) + 3059-3050 (5.9% of area)
50-50.5	6306 ± 40	-25.1	45.3 ± 0.24	-547.1 ± 2.4	7266-7144 (66.5% of area) + 7126-7011 (28.5% of area)

^{210}Pb-inferred ages from 0-16.0 cm support this interpretation. Specifically the corrected unsupported ^{210}Pb concentrations for 16.0 and 18.0 cm are similar (Figure 6.4), which together with an increase in the proportion of mud in the sediment and high total sulphur at 18.0 cm (Figure 6.3) suggests that a large landslip or series of landslips resulted in a rapid deposition of sediment into the lake occurred at this depth, which corresponds to 1922 ± 6.1 years AD. The colour change at 22.0 cm therefore pre-dates 1922. Below 22.0 cm the inferred ages on the stratigraphic diagrams are rough estimates based on linear interpolation between the ^{14}C date at the base of the core and the base of the ^{210}Pb dating.

Figure 6.6: Emerald Lake and its catchment with evidence of landslips.

6.4.3 Diatoms

Ninety diatom taxa were identified in the sediment core. Of these, 74 taxa occurred with a relative abundance of ≥ 1 % in one or more samples and 16 had a maximum relative abundance ≥ 10 % (Figure 6.7). The sediment core was dominated by benthic and epiphytic species (Figure 6.7). The diatom record shows clear species assemblage shifts with marked changes in relative abundance in response to changing environmental conditions.

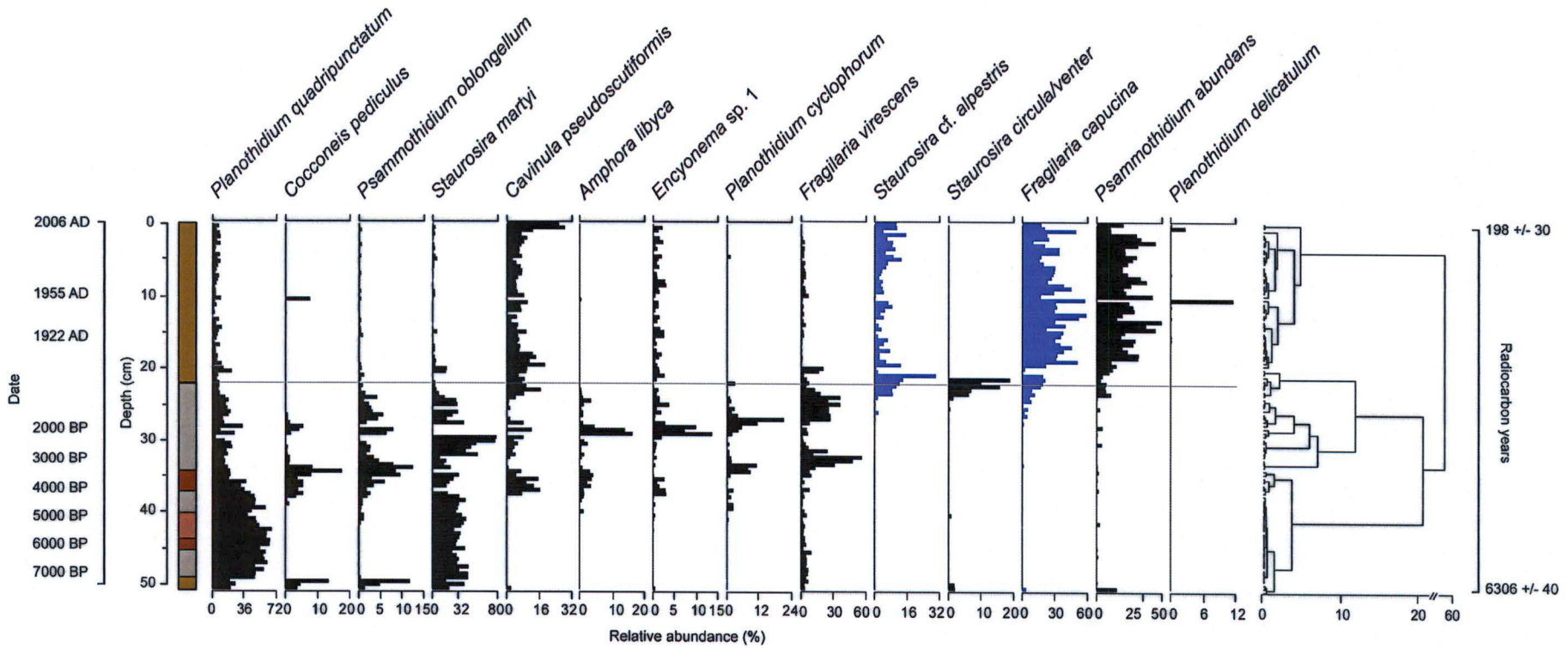


Figure 6.7: Dominant diatoms (i.e. diatoms occurring with a maximum relative abundance ≥ 10% and occurring in ≥ 10 samples) in the Emerald Lake sediment core. Epiphytic diatoms are in blue. The main stratigraphic horizon is marked by a grey line at 22.0 cm. Ages from 0-16 cm are based on ^{210}Pb dating (presented as years AD). Below this point ages are estimated based on linear interpolation between the end of ^{210}Pb dating and ^{14}C inferred age at the base of the core (50.5 cm, c. 7200 calibrated years BP). These are presented as years BP. Diatom assemblage transitions and the radiocarbon dates are also presented on the right hand side. Sediment colour (= light brown, = grey, = brown/red, = brown/red and grey) is also illustrated.

The base of the core (50.0-40.0 cm) was dominated by *Planothidium quadripunctatum* and *Staurosira martyi*. *Cavinula pseudoscutiformis* rapidly increased at 38.0 cm. Clear transitions in diatom assemblages occurred from 35.0-20.0 cm (Figure 6.7). *Cocconeis pediculus* and *Psammothidium oblongellum* peaked c. 34.0 cm. *Fragilaria virescens*, *Amphora libyca*, *Encyonema* sp. 1, *Planothidium cyclophorum* and *Planothidium lanceolatum* showed successive peaks in relative abundance from 32.0-26.0 cm. From 24.0-20.0 cm the diatom flora was dominated by *Staurosira* cf. *alpestris*, *Staurosira venter*, *Fragilaria capucina* and *Cavinula pseudoscutiformis*. From 19.5-0.0 cm, the diatom assemblage was relatively stable and dominated by *Fragilaria capucina* and *Psammothidium abundans*, although a peak in *Planothidium delicatulum* and *Cocconeis pediculus* occurred at 10.5 cm, while *Psammothidium abundans* disappeared despite being abundant throughout the remainder of this section of the core (Figure 6.7).

Species richness (calculated using Simpsons Diversity Index, Simpson 1949) ranged from 0.36-0.96 (Figure 6.8). Periods of lowest species richness occurred at the base of the core (i.e. species richness was 0.48-0.60 from 40.0-50.0 cm) and at 30.0 cm, where species richness reached a minimum of 0.36 (Figure 6.8). During both these periods the core was dominated by *Planothidium quadripunctatum* and *Staurosira martyi*.

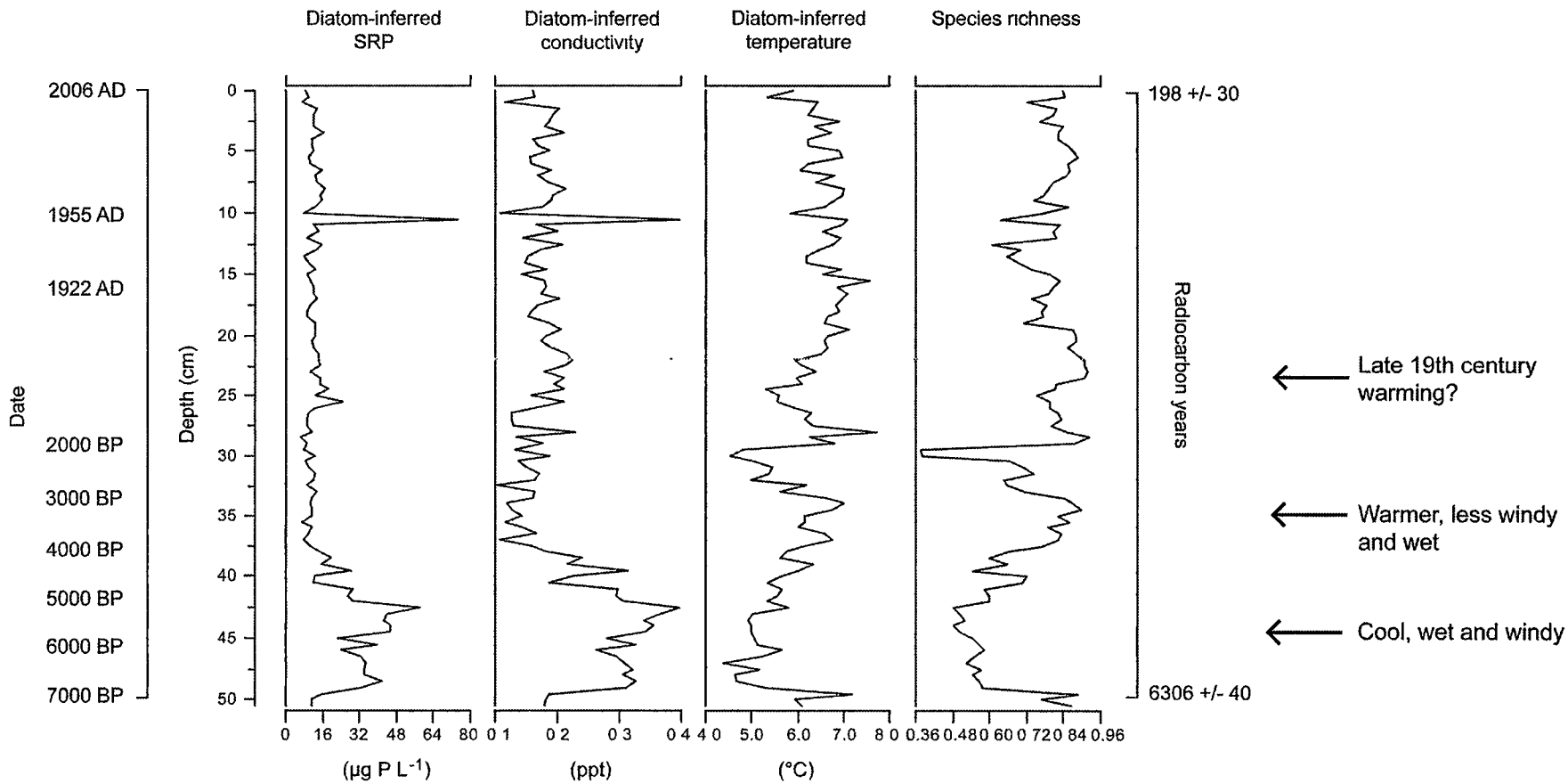


Figure 6.8: Diatom-inferred phosphate, salinity and temperature reconstructions and species richness in the Emerald Lake sediment core. The main stratigraphic horizon is marked by a grey line at 22.0 cm. Ages from 0-16 cm are based on ^{210}Pb dating (presented as years AD). Below this point ages are estimated based on linear interpolation between the end of ^{210}Pb dating and ^{14}C inferred age at the base of the core (50.5 cm, c. 7200 calibrated years BP). These are presented as years BP. Note: SRP = soluble reactive phosphate.

6.4.4 Environmental reconstructions

The diatom-temperature, -conductivity and –soluble reactive phosphate (SRP) transfer functions developed in Chapter 5 were applied to the Emerald Lake sediment core to reconstruct the temperature, conductivity and SRP conditions experienced in the lake over the last 7200 years.

(a) Reconstructed temperature

Diatom-inferred temperature was higher at the base of the core (49.5-50.5 cm), followed by cooler conditions from 49.5-40.5 cm, reaching a minimum at 46.5 cm (4.5 °C ± 1.2 °C). Temperature rose from 40.5 cm to a peak at 34.0 cm (7.0 °C ± 1.2 °C), before reaching a minimum at 30.0 cm (4.6 °C ± 1.2 °C).

This was followed by a brief period of warmer conditions, peaking at 28.0 cm (7.8 °C ± 1.2 °C), before cooling until 24.5 cm. From 24.5 cm onwards, temperature steadily increased until 15.5 cm. From 15.5 cm to the surface, temperature appears to have remained relatively stable, with a slight decreasing trend.

The diatom-inferred temperature record and species richness trend closely followed each other from 50.5-20.0 cm ($r^2 = 0.67$, Figure 6.9), before diverging from 19.5-0.0 cm ($r^2 = 0.00$, Figure 6.8).

(b) Reconstructed conductivity

The diatom-inferred conductivity trend was similar to the diatom-inferred phosphate trend. The base (49.5-50.5 cm) of the core indicated relatively low conductivity (321-419 $\mu S\ cm^{-1}$) conditions. Higher conductivity occurred from 49.0-38.0 cm, peaking at 727 $\mu S\ cm^{-1}$ at 42.5 cm.

Conductivity was lower for the remainder of the core. However, there was a steadily increasing trend from 38.0-20.0 cm. From 20.0 cm to the surface, conductivity averaged 402 $\mu S\ cm^{-1}$ without showing a clear trend, apart from a major peak at 10.5 cm (c. 1950, Figure 6.8).

(c) Reconstructed soluble reactive phosphate

The base (49.5-50.5 cm) of the core indicated relatively low diatom-inferred SRP (c. 10 μg P L^{-1}) concentrations. Higher SRP conditions occurred from 49.0-38.0 cm, peaking at 64 μg P L^{-1} at 42.5 cm.

SRP concentrations were relatively low from 37.0-25.5 cm and averaged ~ 10 μg P L^{-1}. There was a peak in SRP of ~ 30 μg P L^{-1} at 25.5 cm. From 20.0 cm to the surface, SRP was 15-20 μg P L^{-1}, apart from a major peak at 10.5 cm (c. 1950), which appears to be (in terms of the statistics of the reconstruction) a consequence of the sudden brief emergence of *Planothidium delicatulum* and *Cocconeis pediculus* and/or disappearance of *Psammothdium abundans* (Figures 6.7-6.8).

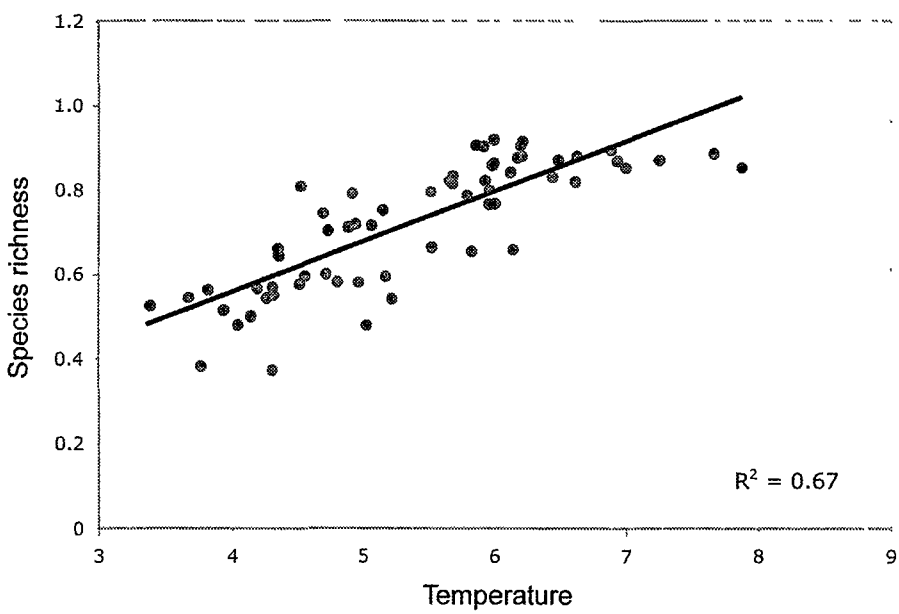


Figure 6.9: Correlation between temperature (°C) and species richness from 50.5-20.0 cm.

6.5 Discussion

Analyses of diatom assemblages, application of diatom-based inference models (i.e. transfer functions) and measurement of physical proxies (i.e. particle size and total sedimentary carbon, nitrogen and sulphur) in the sediment core from Emerald Lake enabled an investigation of Holocene climate variability and

tracking the impact of human arrival and the introduction of feral animals on Macquarie Island.

Below 22.0 cm depth the sediment core from Emerald Lake documents a 7100 year Holocene climate history at Macquarie Island. Above 22.0 cm a substantial change in sediment composition marks a rapid environmental change that likely coincided with human arrival on the island and the introduction of feral animals, in particular rabbits, which resulted in slope instabilities due to vegetation loss and burrowing.

6.5.1 Holocene climate variability on Macquarie Island

Previous studies in both the Northern and Southern Hemispheres, including at high latitudes, have demonstrated that the Holocene has been a period of considerable climate variability (Hodgson *et al.* 2004, Mayewski *et al.* 2004).

The importance of the westerly winds in influencing temperature, precipitation and insolation on past sub-Antarctic climate is widely recognised (Lamy *et al.* 2001, McGone 2002, Bentley *et al.* 2008). However, little is known about the extent and range of past climate variability, including changes in the westerly winds, in the sub-Antarctic zone. Despite this, changes in the westerly winds are implicated in current observed climate changes in the sub-Antarctic and Antarctic (AGCS 2008). Shifts in the latitudinal position of the westerly winds have also been linked to past changes in precipitation in the Southern Hemisphere. Evidence suggests that the westerly winds shifted polewards during the early-mid Holocene (McGlone 2002). Palynological evidence from the sub-Antarctic islands south of New Zealand (Figure 6.1) indicates increased westerly winds and moist conditions occurred after 7000 years BP (McGlone *et al.* 2000). Evidence from South America (at a site located at 41°S) also suggests poleward-shifted westerly winds from 7700-4000 BP (Lamy *et al.* 2001), while Van der Putten *et al.* (2004) found palynological evidence of increased precipitation from 7000-4000 years BP on South Georgia.

The diatom, particle size and geochemical records from Emerald Lake in the early-mid Holocene (50.0-40.0 cm, c. 7200-4400 calibrated years BP) indicated relatively cool conditions, greater wind strength and possibly higher precipitation (Figures 6.7-6.8). This period was dominated by *Planothidium*

quadripunctatum and *Staurosira martyi*. *Planothidium quadripunctatum* is a common benthic diatom, which can sometimes dominate diatom flora and has a preference for higher specific conductance, and *Staurosira martyi*, which is influenced by birds and sea spray and consequently has higher nutrient and conductivity preferences (Van de Vijver *et al.* 2002b). This suggests a period of higher conductivity and possibly nutrients in the lake. This is supported by reconstructed SRP and conductivity, which were also higher during this time, suggesting a period of relatively high precipitation and wind (Figure 6.8). Additionally, species richness was relatively low, as was reconstructed temperature (Figure 6.8). The high proportion of coarse grained material, in particular silt, also suggests high wind strength, cool temperatures and greater precipitation leading to more rapidly flowing streams able to carry larger sediment particles to the lake (McGlone *et al.* 1997), while low total nitrogen and total carbon and low sedimentation rates indicate a relatively unproductive system. In general, the sedimentary evidence of the early-mid Holocene environment on Macquarie Island is consistent with relatively cool, wet and windy conditions (Figure 6.8).

In addition, the relatively high levels of reconstructed phosphate (i.e. max 64 μg P L^{-1}) in the lake sediment also suggest that a bird population may have resided in the lake's catchment (Figure 6.8). In the reference dataset, the only inland sites with an animal population within their catchments had phosphate concentrations > 30 μg P L^{-1} (e.g. sites 6, 19, 20, 26), while all others had lower values. Currently phosphate in Emerald Lake is 13-18 μg P L^{-1} (unpublished data).

A change in the diatom assemblages and reconstructed variables occurred at 40.0 cm (c. 4400 calibrated years BP). The clear successional changes in the diatom record from 40.0-22.5 cm (starting c. 4400 calibrated years BP) indicate relatively undisturbed sediments and the development of the diatom lake community in response to the changing environment (Douglas *et al.* 1994). The reduction in reconstructed phosphate and conductivity is consistent with less windy and wet conditions, while the increased species richness and reconstructed temperature are consistent with warmer temperatures for this period. The general decrease in the C:N mole ratio from 40.0-20.0 cm may reflect decreased rainfall and thus runoff into the lake (Michelutti *et al.* 2005). This suggests that the mid-

late Holocene period on Macquarie Island seems to have been relatively warm, dry and less windy and is consistent with evidence in palaeolake deposits on Macquarie Island of drier conditions from 5000-3000 years BP (Keenan 1995) and from the maritime Antarctic and elsewhere in Antarctica for a warm period at approximately this time (Jones *et al.* 2000, Hodgson *et al.* 2004, Hodgson & Convey 2005, Bentley *et al.* 2008).

The late Holocene climate (i.e. since 4000 BP) of the sub-Antarctic was generally characterised by lower precipitation. Lamy *et al.* (2001) suggested that the westerly winds moved equatorward around 4000 BP. Warmer conditions are thought to have occurred during this period on the South Shetland and James Ross Islands, maritime Antarctic islands including Signy Island (i.e. 4000-2700 years BP) and on sub-Antarctic South Georgia (i.e. 4400-2400 years BP, Bentley *et al.* 2008). Palynological evidence from the sub-Antarctic islands south of New Zealand indicates a warm period occurred from 6000-3000 years BP and drier conditions and increased summer insolation occurred after 3000 years BP (McGlone 2002, Figure 6.1). The sediment record from Macquarie Island documents a rapid and brief period of lower temperatures and reduced species richness at 30.0 cm (c. 2000 calibrated years BP, Figure 6.8), which corresponds with the onset of cooler and wetter conditions reported at South Georgia after 2250 years BP (Van der Putten *et al.* 2004) and may reflect a regional sub-Antarctic period of cooler conditions in the late Holocene.

Thus, this record from Macquarie Island is complementary to previously published sub-Antarctic climate records for the Holocene, indicating that the early-mid Holocene period on Macquarie Island was relatively wet, windy and cool, with low to moderate species richness, while the mid-late Holocene climate of Macquarie Island was relatively warm, dry and less windy, with greater species richness, although there also appears to be a brief period of cooler and wetter conditions c. 2000 years BP (Figures 6.7-6.8)

6.5.2 Human arrival on Macquarie Island: establishing baseline conditions

The visual stratigraphy, chronology and geochemistry of the Emerald Lake sediment core record shows that substantial changes occurred from 22.0-16.0 cm. Below this depth, the sediment was deposited over approximately 7100 years,

while the top 16 cm was deposited in c. 84 years. This also suggests that the 6.0 cm below 16.0 cm is likely to have been deposited during the 19th century and/or early 20th century. This coincides with human arrival on Macquarie Island and introduction and establishment of non-indigenous species. ^{14}C dating at 22.0 cm depth indicated an old (> 2000 years BP) age of the sediment and older carbon is likely to have been incorporated into the sediment as a consequence of rapidly increased sediment input from the catchment. The massive change in sedimentation rate led to a brief period of anoxic conditions c. 1922 AD (as implied by a peak in total sulphur content and increase in mud, Figure 6.3). This may be due to slope instability and enhanced sediment inputs causing anoxia to develop within the surface sediments.

The near disappearance of *Staurosira martyi* and dominance of *Staurosira* cf. *alpestris*, *Staurosira venter*, *Fragilaria capucina* and *Cavinula pseudoscutiformis* from 24.0-20.0 cm also suggests the lake experienced a series of substantial changes in environmental conditions and influences at this time. A clear change in the diatom composition occurred at 20.0 cm (Figure 6.7) with a shift to a diatom assemblage not recorded in the previous c. 7100 years. Small benthic *Fragilaria* and *Staurosira* species are frequently abundant in cold waters and are dominant in arctic and alpine lakes (Douglas & Smol 1999). These taxa are rapid colonisers with high reproductive rates, which make them more adaptable to changing environmental conditions associated with rapid sedimentation rates (Lotter & Bigler 2000). Interestingly, three of the four abundant diatom species during this time were also present at the very base of the core. However, further sediment core collection extending further back into the early Holocene is needed to determine what this period was like and if it can potentially be an analogue for the present.

Both *Staurosira* cf. *alpestris* and *Fragilaria capucina* are epiphytic diatoms (Van de Vijver *et al.* 2002b). *Staurosira* cf. *alpestris* was not present in the sediment record prior to this, while *Fragilaria capucina* was only recorded twice (both with low relative abundance, Figure 6.7). The dominance of these species suggests the establishment of macrophytes in the lake and possible lake shallowing due to enhanced sediment input and the formation of shoreline delta deposits. Schindler and Smol (2006) suggested that climate warming in the Arctic (in the early-mid 19th century) resulted in changes to habitat availability, including

an increase in filamentous algae. The establishment of aquatic macrophytes, as suggested by the increase and dominance of *Staurosira* cf. *alpestris* and *Fragilaria capucina*, may provide some evidence of warmer temperatures on Macquarie Island during this time. This is supported by the temperature reconstruction, which indicates a steadily rising trend from 24.0-15.5 cm. The diatom assemblage of the upper section of the core was relatively stable and dominated by *Fragilaria capucina* and *Psammothidium abundans*. The dominance of *Fragilaria capucina* suggests continued macrophyte occurrence.

6.5.3 Introduction of feral animals

Rabbits and weka were introduced in 1878 and 1880 respectively, while rats and mice were first recorded in the 1890s (Scott 1988, PWS 2007). Weka were mostly found around the coast and were eradicated in 1989 (Taylor 1955, PWS 2007). In 1880, rabbits were reported as 'swarming' on the northern part of the island (Scott 1880 in Law & Burstall 1956) but were reported to have disappeared by 1894 due to feral cats (Hamilton 1894 in Law & Burstall 1956). It is likely that continued expansion of these feral populations and particularly the devegetation and burrowing activities of rabbits contributed to increased erosion, causing slope failures and a major increase in sediment inputs into Emerald Lake. Additionally, Macquarie Island frequently experiences earthquakes, which also causes landslides on the island (Scott 1988). One of the major earthquakes to affect Macquarie Island during the 20th century occurred in 1924 (Jones & McCue 1988). This, together with devegetation and burrowing by rabbits may have led to landslips and large amount of sediment deposited into the lake from 16.0-18.0 cm, causing a period of benthic anoxia (Figure 6.3, 6.4). Evidence of this extensive erosion and landslips are widespread on Macquarie Island, including in the Emerald Lake catchment (Figures 6.6 and 6.10).

(a)

(b)

Figure 6.10: (a) Evidence of erosion below the Emerald Lake catchment and (b) widespread evidence of landslips along the west coast of the island. Evidence of Emerald Lake slope instability is presented in Figure 6.6.

There are some observational records of changing rabbit populations on the island during the late 19th and early 20th centuries (e.g. Mawson 1943, Taylor 1955, Cumpston 1968). While rabbits were reported as widespread in the northern part of the island from 1880-1894, their populations are reported to have fluctuated markedly from 1894-1919 and in 1923 no rabbits were observed on the northern end of the island (Cumpston 1968). During Mawson's expedition between 1911 and 1914, numerous rabbits were reported at all points along the east coast, although the severely grazed area only extended between Lusitania Bay and Waterfall Bay, and no rabbits were observed on the west coast (Mawson

1943, Figure 6.11). Between 1948 and the early 1960s rabbits were scarce on the northern end of the island. In 1948, the greatest concentration of rabbits was still around Lusitania Bay and Waterfall Bay, in 1949 it was around Green Gorge, in 1950 it was between Bauer Bay and Sandy Bay. By the end of 1950 the concentration of rabbits had extended northwards by almost 1 km. In 1951, the greatest concentration of rabbits was around Flat Creek (Taylor 1955, Figure 6.11). Emerald Lake is just north of the area between Bauer Bay and Sandy Bay and the catchment may have experienced increased rabbit numbers towards the end of 1950.

There is a sudden change in the diatom composition of the Emerald Lake sediment core at 10.5 cm (c. 1955). At this time the Emerald Lake catchment would have been near the advancing line of rabbits. Prolonged and extensive grazing would have led to reduced vegetation cover and increased nutrient, erosion and sedimentation rates into the lake consistent with rabbit induced landscape instability. The brief period of changed diatom composition and inferred higher SRP concentration and conductivity may be a reflection of the rabbit population progressing to and past the Emerald Lake catchment. A period of greater sediment input is also indicated in the geochemical record where there is a spike in the C:N mole ratio, suggesting increased input from the catchment. This is also reflected in the unsupported ^{210}Pb profile, which indicates a more rapid period of sedimentation from 10.0-6.0 cm (c. 1949-1970, Figure 6.4). This period corresponds to the time when rabbits are reported to have been common and abundant in the vicinity of Emerald Lake (Scott 1988) and spans the period of rapid expansion in population numbers, which was estimated to increase from 50,000 in 1956 to 150,000 in 1965-1966 (Sobey *et al.* 1973 in Scott 1988).

The sedimentation rate slowed from 6.0 cm to the surface of the core (i.e. c. 1970-2006). The introduction of the myxoma virus in 1978 to control the rabbit population led to a marked decrease in rabbit numbers and signs of vegetation recovery during the 1980s and 1990s (Scott 1988, PWS 2007, Scott & Kirkpatrick 2007). This, together with natural recovery and revegetation of the catchment following the heavy grazing and slope erosion, may have led to a decline in the volume of material entering the lake and decrease in sedimentation rate.

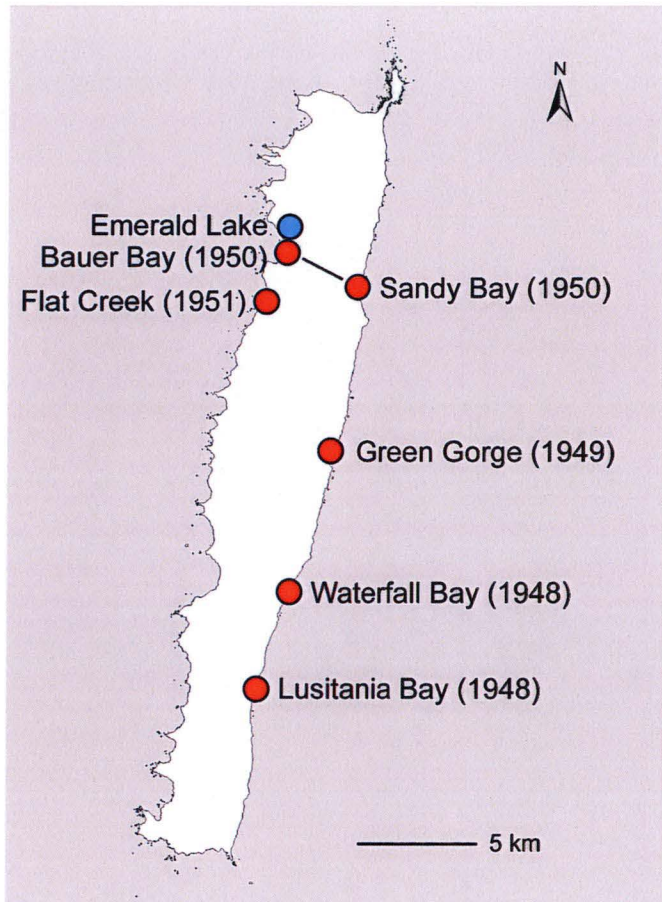


Figure 6.11: Location of sites following the progression of the rabbit population across Macquarie Island. Rabbits were introduced to Lusitania Bay in 1880. In 1948, the greatest concentration of rabbits was between Lusitania Bay and Waterfall Bay, by 1949 the main population was around Green Gorge, by 1950 it was between Bauer Bay and Sandy Bay; and by 1951 the main population was around Flat Creek. Emerald Lake is shown in blue.

There was a large increase in the C:N mole ratio at the surface of the sediment core, suggesting a recent increase in sediment input derived from the catchment (Figure 6.3). *Planothidium delicatulum* also appears in the surface sample (Figure 6.7). The only other appearance of *Planothidium delicatulum* was at 10.5 cm (c. 1955), which occurred at the same time as the rabbit population is likely to have advanced to and past the Emerald Lake catchment. Monitoring of rabbit numbers on the island has indicated a dramatic increase since 1999 (PWS 2007). Reasons include the removal of cats, which were a major predator, increasing resistance to the myxoma virus and successively warmer winters, possibly contributing to extended breeding seasons and survival of rabbits (PWS 2007). Monitoring of vegetation on the island since the introduction of the

myxoma virus found that 15 years after severe grazing was stopped, in some cases the vegetation had almost completely recovered, but with increased grazing pressure since 1999, by 2002-2003 the situation had reversed (Scott & Kirkpatrick 2007). It is likely that recent increased rabbit grazing and burrowing pressures on the Emerald Lake catchment have again led to increased erosion and nutrients (total nitrogen) into the lake.

In summary, the Emerald Lake sediment core provides a 7100 year climate history of Macquarie Island, followed by c. 100 years of rapidly deposited sediment containing a diatom assemblage different to any assemblage deposited in the last 7000+ years. This is interpreted as a response to human arrival on the island and the introduction of feral animals, in particular rabbits, which have caused landscape instability. This also coincides with a period of sustained warmer (diatom-inferred) temperatures (Figure 6.8).

6.5.4 Implications for the future

Recent human impacts including anthropogenically driven climate change and introduced species are currently overriding many natural processes in the sub-Antarctic (Convey 2007).

There is little doubt that the climate in the sub-Antarctic is changing, at least over the short to medium term. There is evidence of air, sea surface and mid-depth ocean warming in the region since the mid 20th century (Pendlebury & Barnes-Keoghan 2007). Temperature records from Macquarie Island indicate a 0.3°C increase in mean surface air temperature since the 1950s (Tweedie & Bergstrom 2000), although there has been no obvious trend since the 1980s (Pendlebury & Barnes-Keoghan 2007, Figure 6.12). The removal of feral animals and predicting the response of Macquarie Island's biota to predicted warmer climates provide major conservation and management challenges.

The weather systems of the sub-Antarctic are driven by westerly wind patterns. Broad scale changes to weather systems, in particular the Southern Annular Mode (SAM) and El Niño Southern Oscillation (ENSO), are important contributors to sub-Antarctic climate (Pendlebury & Barnes-Keoghan 2007).

SAM is the dominant mode of climate variability in the Southern Hemisphere and is likely to have a greater influence on sub-Antarctic climate than

ENSO, as the influence of ENSO decreases with increasing latitudes (Ummenhoffer & England 2007, Hill *et al.* 2008). The SAM primarily results from the global meridional temperature gradient between high and low latitudes (Cai & Watterson 2002, Thompson & Wallace 2000). Negative SAM results in anomalously high pressure at 40°S and 65°S, while positive SAM results in anomalously high pressure at 40°S and low pressure at 60°S. Positive SAM leads to relatively dry conditions over some northern parts of the sub-Antarctic and wetter and windier conditions over southern regions (Marshall *et al.* 2006). More positive SAM conditions coincide with a more southerly position of the westerly wind maxima, while negative SAM years are due to a northerly shift in the westerlies (Hill *et al.* 2008). Since 1965, trends in SAM exceeded natural modelled climate variability, which has been attributed to a combination of anthropogenic and natural forcings and may be the cause of increased westerly winds in the region (Marshall *et al.* 2006, Pendlebury & Barnes-Keoghan 2007). Marshall *et al.* (2006) have demonstrated that the current rising temperature trend in the northern Antarctic Peninsula region, which may also apply to the sub-Antarctic, is probably due to increased westerly wind strength, driven by increased greenhouse gas concentrations. This is also likely documented in the Emerald Lake sediment core as diatom-inferred temperatures have risen during the last 100 years (Figure 6.8) and measured temperatures have increased between 1950 and 1980 (Tweedie & Bergstrom 2000).

The increase in temperature in the sub-Antarctic has led to an increase in rainfall in the Southern Ocean, which has been observed indirectly through measurements of a freshening signal in the North Pacific Intermediate Water and Antarctic Intermediate Water (Wong *et al.* 1999). Observations at the surface of the Southern Ocean are currently too sparse to directly measure this effect on a broad geographical scale, however rainfall trends recorded at Macquarie Island since 1950 indicate higher total annual rainfall since the 1980s (Figure 6.12). However, it is important to note that increased rainfall is not consistent throughout the sub-Antarctic: Marion Island and Îles Kerguelen have experienced a decrease in rainfall over the same period (Smith 2002).

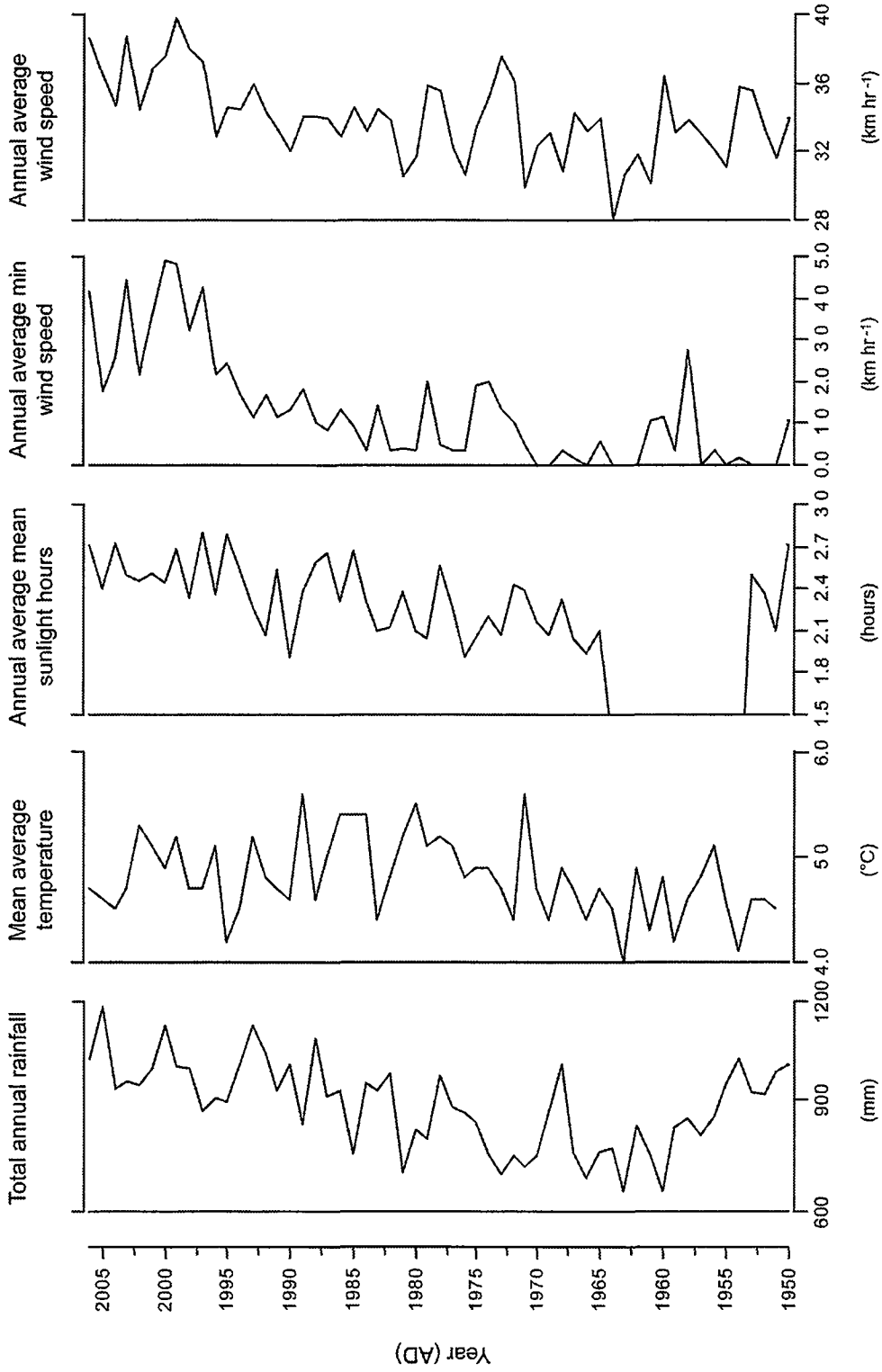


Figure 6.12: Annual average weather observation data recorded at Macquarie Island from 1949-2006. Total annual rainfall, mean annual air temperature, annual average sunlight hours and wind speed, particularlyminimum wind speed, have all increased since records began in 1949 (modified from raw data supplied by BOM 2007).

A possible explanation for this difference is that a southerly shift in tropospheric baroclinicity has occurred and it is possible that the latitude of peak intensity of rain-bearing systems has moved southwards and away from latitudes represented by Marion Island (~ 47 °S) to latitudes represented by Macquarie Island (~54 °S, Pendlebury & Barnes-Keoghan 2007). This is also supported by

rainfall evidence from Tasmania, which shows an overall drying trend during the 20th century that has been linked to southward migration in the mean latitude of extratropical cyclones (Hill *et al.* 2008). Sea surface temperature and surface ocean anomalies appear to respond directly to these wind anomalies, suggesting rainfall variations are largely due to direct atmospheric forcing by the wind stress field (Hill *et al.* 2008). Whitlock *et al.* (2007) have also found evidence of southward shifted westerlies in South America in recent years.

Consequently, increasing temperatures and shifts in the position of westerly wind patterns result in changes in wind speed, precipitation and temperature regimes on sub-Antarctic islands and may be causing the observed increases in total annual rainfall, average temperature, wind (in particular minimum wind speeds) and sunshine hours recorded at Macquarie Island since 1949 (Figure 6.12).

It is thought that with the eradication of rabbits and rodents, ecosystem recovery will occur without the need for large scale proactive rehabilitation, although some of the most severely damaged areas may take a long time to recover and in some cases damage may be irreversible (Scott *et al.* 2007). The three desired outcomes of rabbit and rodent eradication are:

(i) establishment of healthy vegetation across the island;

(ii) stabilisation of albatross breeding slopes; and

(iii) reestablishment of burrow-nesting petrels on the island (Springer 2008)

Macquarie Island is a World Heritage listed site. It was listed for its natural values (Scott *et al.* 2007). These values are currently under threat and will continue to be until the island is able to recover. Macquarie Island is one of 31 out of 830 World Heritage sites currently on the 'List of World Heritage in Danger' (UNESCO 2007). Of these sites, only the Everglades World Heritage Area in the USA is also in a developed country (Scott *et al.* 2007). Achieving the three aims listed above requires understanding past biodiversity and ecosystem responses in relation to climate variability. Further work is needed to determine what the current extent and rates of changes of Macquarie Island's climate are (i.e. rainfall, wind and sunshine as well as temperature) and whether these are within the natural boundaries of climate variability. There is some debate as to how much Macquarie Island's climate is currently changing. The climate trends of

Macquarie Island and sub-Antarctic during the 20th century are not fully understood and a longer term perspective, provided by a palaeoecological approach, is needed.

6.5.5 Implications for palaeolimnological studies of climate change on Macquarie Island

While each island in the sub-Antarctic will have its own precipitation regime, Macquarie Island is arguably the best representative of the area between the Polar and sub-Antarctic Fronts (Pendlebury & Barnes-Keoghan 2007). As Macquarie Island was only discovered by humans in 1810 and was not extensively glaciated during the Last Glacial Maximum (Selkirk *et al.* 1990), lake sediment records have the potential to hold long climate records without confounding signals from long term human presence.

For the more recent climate record, however, it is very likely that the Emerald Lake sediment climate signal has been overridden by the substantial increase in sedimentation rates and erosion since the arrival of humans and introduction of feral animals. Thus, although the temperature reconstruction based on the Emerald Lake sediment core indicated a rising trend from 24.0-15.5 cm (until c. 1937 AD) this trend did not continue to the surface (Figure 6.8), despite measured air temperature records indicating a rise of 0.3 °C since 1949 (Tweedie & Bergstrom 2000, Figure 6.12). There is also no clear trend in either the SRP or conductivity reconstructions (Figure 6.11). This may also be a consequence of the location of the weather monitoring site at Macquarie Island, which is at sea level on the northern end of the island, whereas the lake in this study sits on the western edge of the plateau, 170 m above sea level. This means the recorded weather observations at low altitude may not reflect those experienced high on the plateau, which is often shrouded in cloud. The disconnect is also implied by the species richness and diatom-inferred temperature trends in the Emerald Lake sediment core. Species richness has previously been found to be correlated to temperature (Korhola & Weckström 2004). In this study, species richness and temperature followed similar trends from 50.0-20.0 cm ($r^2 = 0.67$), however from 19.5-0.0 cm they did not (Figures 6.8 and 6.9). This suggests that there is a clear climate signal reflected in the diatom record prior to 19.5 cm, with diatom community responses

to changes in temperature recorded in the Emerald Lake sediment core. However, during the 20th century the measured climate trends are not reflected in the diatom record as no obvious trends in species composition, species richness or reconstructed variables were observed (Figures 6.7 and 6.8).

Further palaeolimnological analyses of additional lakes on Macquarie Island will potentially allow the development of longer climate records, particularly extending through the Last Glacial Maximum. A series of cores at different altitudes and distances from the west coast may allow changes in wind strength, direction and precipitation regimes to be determined. This would provide valuable information on past Macquarie Island climates and climate thresholds, contribute to understanding past sub-Antarctic climate changes and allow assessments of regional climate in the Southern Hemisphere. It also offers an opportunity to link sub-Antarctic climate records with the development of a global network of palaeoclimate records that are being used to examine the linkages between the Northern and Southern Hemisphere climates (Hodgson *et al.* 2007).

The sediment record from Emerald Lake indicates periods of warmer and cooler temperatures, different amounts of precipitation and wind strengths throughout the Holocene. Warmer periods than the present occurred on Macquarie Island during the mid-Holocene (Figure 6.8). This has been found elsewhere in the sub-Antarctic and Antarctic (e.g. see Hodgson *et al.* 2004 for a review). This implies that the current temperature regime is still within the Holocene temperature 'thresholds' previously experienced by Macquarie Island's biota. Further work is required to determine wind and precipitation 'boundaries' for Macquarie Island climate to determine whether current conditions have occurred in the past and if so, when and what the consequences were, and importantly, what past rates of change in wind, precipitation and temperature have occurred, and how they compare with current and predicted trends.

Macquarie Island ecosystems have changed dramatically since human arrival and even with the eradication of feral animals, introduced plant species will play an increasingly important role on Macquarie Island ecosystems and biodiversity. Evidence suggests that the introduced plant species rapidly colonise the exposed areas left by feral animals and can out-compete the native flora (Taylor 1955, PWS 2007), but they do not usually dominate for long before the native flora takes over (Springer 2008). However, with warmer temperatures, it

will be important to monitor the spread of introduced plant species in relation to the native flora once feral animals have been removed. The potential for ecosystem recovery on sub-Antarctic islands after the removal of feral animals is uncertain (Convey 2007), however studies on Macquarie Island have demonstrated that if a rabbit grazed area is excluded from further grazing, it does become re-vegetated (PWS 2007).

6.6 Conclusions

In summary, the sediment core evidence including the diatoms and diatom-based reconstructions have provided a valuable insight into the climate of Macquarie Island during the Holocene and evidence of natural climate variations. The diatom record, diatom-inferred environmental reconstructions, geochemistry and particle size data suggest relatively wet, windy and cool conditions existed on Macquarie Island during the early Holocene, while the mid Holocene was generally warmer and less windy and wet. The arrival of humans and introduction of feral animals, in particular rabbits, coincided with a warming trend (as inferred by the diatom-based temperature reconstruction) and increased sediment input into the lake.

The palaeolimnological evidence from Macquarie Island has a valuable role to play in conservation planning as it provides an historical context within which to interpret the significance of present-day climate and environmental change and a quantitative basis for predicting the impact of future change. More generally, palaeolimnological records offer an opportunity to link Antarctic, Southern Ocean and Southern Hemisphere climate records and be integrated with Northern Hemisphere climate records to contribute more generally to understanding global climate change and the influence of major weather systems such as the southern westerlies.

This study has provided a clear understanding of baseline conditions prior to human arrival on Macquarie Island and a benchmark against which to monitor ecosystem responses following the eradication of rabbits and rodents. This offers an opportunity for managers to strive towards achieving Mawson's vision that the future conservation and management of Macquarie Island '...should provide not only for the complete protection of the native fauna and flora but all possible steps

should be taken to repair the ravages of the past and eliminate all introduced creatures…' (Mawson 1943: 43).

General Discussion: Integrating palaeolimnology into Australian ecosystem management

Environmental degradation, in particular deteriorating water quality resulting from direct and indirect human impacts, is a worldwide problem. Increasingly, human activities are being shown to be causing ecosystem changes that are well beyond the ranges of natural variability (e.g. IPCC 2007). Understanding past environmental changes and setting realistic conservation targets is recognised by scientists, environmental managers and policy makers alike as a major challenge, and a fundamental component of developing successful management strategies. The aim of many management strategies is to prepare for predicted changes and restore to or maintain ecosystems in a 'healthy' condition. To achieve this requires careful consideration of what is 'healthy' and importantly, what is a realistic. This requires accurate baseline data, understanding the nature, causes and direction of changes, at what point in time and at what level of disturbance negative impacts became apparent, and importantly, determining ranges of natural variability. It is also important to consider social and economic needs to determine what is realistic. The need for a long temporal perspective is of central importance to this process and, consequently, palaeolimnological studies have a key role to play in the development of future aquatic ecosystem management strategies.

The Aims of this Thesis were to apply a palaeolimnological approach to two contrasting aquatic environments with different environmental problems and human impact histories. One site was a southeast Australian estuarine system (Chapter 4), while the other was a sub-Antarctic lake (Chapter 6). The overall objective was to demonstrate the value of palaeolimnological approaches, based on diatom transfer functions, to identify the impacts and consequences of human activities and provide a context for future management strategies.

Palaeolimnological studies that reconstruct environmental conditions prior to, during and after specific human impacts and/or land and water management practices can provide valuable information regarding the state of the environment and responses to these impacts. Based on this, realistic baselines and management targets can be set within a context of understanding natural variability and how the modern environment has developed and been influenced.

To demonstrate the value of palaeolimnological approaches for addressing Australian estuarine water quality issues over relatively short timescales (i.e. 100-200 years), diatom reference datasets consisting of surface sediment diatom species and water quality data collected from coastal lakes, lagoons and estuaries in Tasmania and Victoria were developed (Chapter 3). This is one of the first applications of a palaeolimnological approach to reconstructing nutrient concentrations and salinity in an Australian estuary. Phosphate concentrations and salinity were found to significantly influence diatom species assemblages in both Tasmania and Victoria. When the datasets were combined, latitude and to a lesser extent, longitude, significantly influenced diatom species assemblages, highlighting the influence of geographic variability on diatom taxa in southeast Australian coastal water bodies. This indicated that the datasets should be used separately to develop specific transfer functions for Tasmania and Victoria. The Victorian phosphate transfer function performed well ($r^2p = 0.62$), while the Tasmanian phosphate transfer function had poor predictive ability ($r^2p = 0.20$). Both the Tasmanian and Victorian salinity transfer functions performed moderately well ($r^2p = 0.36$ and $r^2p = 0.45$ respectively), but had worse predictive ability than previously published salinity transfer functions, highlighting the influence of multiple environmental variables on diatom species in these datasets. The phosphate and salinity transfer functions developed from the Victorian dataset were applied to a sediment core from Lake King, Gippsland Lakes, Victoria and used to assess future management options (Chapter 4).

The Gippsland Lakes have been extensively modified since European settlement, leading to degradation in water quality and improving the water quality of the Gippsland Lakes has become an important issue. Major environmental issues include high nutrient concentrations (from direct and diffuse sources), algal blooms, declining freshwater macrophyte communities (particularly freshwater marshes), shoreline erosion, reduced suitable habitat for waterbirds, stratification and anoxic bottom waters, and introduced exotic plants and animals (Webster *et al.* 2001, Winstanley 1995). An artificial channel between Lake King and the sea was constructed in 1889 to aid shipping in the area. Subsequently, the salinity of the lakes has increased and they regularly experience stratification (Bird 1993, Winstanley 1995). The hydrology of the Gippsland Lakes, as they are today, is a relatively recent phenomenon and prior to

this study, little was known about the 'baseline' status of the lakes prior to the permanent entrance or the rate and extent of ecological and water chemistry changes since it was constructed.

Changes in diatom assemblages of the Lake King sediment core recorded a shift from a brackish-water to marine diatom flora following the construction of the permanent entrance. Application of the phosphate and salinity diatom transfer functions showed that concentrations of phosphate increased during the early European settlement period, followed by peaks in the late 1930s, c. 1945 and late 1950s. Analyses of chlorophyll *a* indicated clear increases in sediment chlorophyll *a* content have occurred since the 1980s (to a maximum of 120 $\mu g\ L^{-1}\ gTOM^{-1}$), likely associated with an increase in the frequency and intensity of algal blooms. Collectively these data showed that the ecology of Lake King is now very different to that present during early European settlement and provide valuable baseline data for future management by providing information on the pre-permanent entrance ecology of the lake, the impact of the permanent entrance, changes in phosphate concentrations and salinity over the last 100 + years, together with evidence that supports the presence of algal blooms throughout the record (Chapter 4).

Based on this palaeolimnological study of Lake King, recommendations for the future management of the Gippsland Lakes include:

- Aim to reduce known point source inputs of phosphate into the Gippsland Lakes and consequently,
- Aim to reduce, but not eliminate, algal blooms (as algal blooms have occurred naturally).
- Accept that as a result of the permanent entrance the salinity of Lake King will remain elevated above its natural state.
- Encourage restoration of native macrophyte, littoral and shoreline plant communities to maintain biodiversity.

To demonstrate the value of palaeolimnological approaches over a longer timescale to determine natural variability and assess the impacts of introducing feral animals into an ecosystem, a palaeolimnological approach based on a sediment core from sub-Antarctic Macquarie Island was carried out. This was supported by a diatom reference dataset developed from sub-Antarctic Macquarie

Island coastal and inland lakes (Chapters 5 and 6). This study is one of the first applications of a palaeolimnological approach to reconstructing climate variability on Macquarie Island and the first to use a palaeolimnological approach to assess the impact of introducing feral animals. Little is known about the major environmental gradients occurring in the lakes of Macquarie Island, the diatom species that occur or their ecological preferences. This study provided baseline, species-level data on the composition and distribution of surface sediment diatom communities of Macquarie Island lakes, and demonstrated that pH, phosphate, conductivity, silicate and temperature significantly influenced diatom species assemblages. Thus, phosphate, conductivity and temperature transfer functions were developed and applied to a sediment core from Emerald Lake, northwest Macquarie Island (Chapter 6).

Analyses of diatom assemblages, reconstructed phosphate, conductivity and temperature, and total sedimentary carbon, nitrogen and sulphur indicate that a relatively stable environment existed for 7100 years (average sedimentation rate ~ 0.004 cm yr^{-1}), above which lay 100 years of rapidly deposited sediment (average sedimentation rate 0.34 cm yr^{-1}, maximum 0.74 cm yr^{-1}), indicating sudden, rapid erosion within the lake's catchment.

The sediment record indicated periods of warmer and cooler temperatures, different amounts of precipitation and wind from 7200 years ago to present. Warmer periods than the present occurred on Macquarie Island during the mid-Holocene; this has also been found elsewhere in the sub-Antarctic (e.g. Van der Putten *et al.* 2004) and Antarctic (e.g. Hall *et al.* 2006). This implies that the current temperature regime is still within the Holocene temperature 'thresholds' previously experienced by Macquarie Island's biota. However, with the arrival of humans and feral animals, Macquarie Island's ecosystems have changed dramatically. This was also reflected in the sediment record. The diatom assemblage in the lake changed markedly and became dominated by epiphytic species, while total sedimentary carbon and nitrogen increased and a period of anoxic conditions occurred (inferred from a peak in total sulphur). Since human arrival, several mammal and bird species have become extinct or have greatly reduced in numbers and many have been introduced. Of most importance, cats were introduced in the early-mid 19^{th} century and soon became feral, which led to the extinction of the endemic ground birds, while rabbits were introduced in the

late 19th century and, after an initial slow spread, are currently having a devastating effect on the island. The transition in sedimentation rates, diatom assemblages and geochemical record in the sediment core coincide with the arrival of humans and introduction of cats, followed by rabbits. Cats were finally eradicated in 2000 and recently, planning to eradicate the rabbits and rodents began. While current climate conditions are within the boundaries of Holocene natural variability, with predictions of warmer temperatures and the eradication of these feral animals, introduced plant species will play an increasingly important role in Macquarie Island ecosystems. Once the feral animals have been removed, it will be important to monitor sediment mobility and input into the lakes and the spread of introduced plant species in relation to the native flora and monitor the recovery of the island. Understanding natural variability, sediment mobility and what was present prior to human arrival is an essential component of the restoration and rehabilitation process of Macquarie Island.

Present management strategies are focused on the present and future state of Macquarie Island. For the present, management strategies are focused on eradicating the rabbits and rodents. In the future management strategies will be focused on monitoring the outcomes of this eradication process. A fundamental component of this is establishing accurate baseline information. The only way to determine the baseline condition of Macquarie Island and provide baseline information for ongoing long term monitoring is to use a palaeolimnological approach to establish environmental conditions prior to the introduction of rabbits and rodents in the 1800s. In particular, vegetation reconstructions alongside diatom studies would provide a context for the natural state of Macquarie Island.

In addition, based on this palaeolimnological study of Emerald Lake, future monitoring and management of Macquarie Island should include:

- Continue to monitor diatom-inferred temperatures to determine when/if these exceed the range of natural (Holocene) variability;
- Monitor catchment recovery and sediment inputs into the lakes;
- Establish baseline (i.e. pre-impact) conditions in a range of lakes on the island that represent the full spectrum of variability in Macquarie Island ecosystems
- Use these baseline conditions to develop strategies and set targets for habitat restoration.

This Thesis has demonstrated the value and wide ranging applicability of diatom-based transfer functions and a palaeolimnological approach to identify the impacts and consequences of human activities in order to provide a context and recommendations for future management strategies. As outlined in Chapter 1, previous studies have also used palaeolimnological approaches to investigate environmental problems, answer management questions and confirm or negate assumptions by providing qualitative and quantitative data to determine the causes and impacts of lake acidification (e.g. Battarbee 1990), eutrophication (e.g. Bennion 1994), salinisation (e.g. Gell *et al.* 2005) and detecting climate change (Bangs *et al.* 2000, Rosen *et al.* 2000, Battarbee *et al.* 2002, Kershaw *et al.* 2007, Smol & Douglas 2007). However, widespread integration and adoption of palaeolimnological techniques into Australian ecosystem management is still in its infancy.

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Palaeolimnology as a Management Tool for Australian Aquatic Ecosystems

Appendices

Krystyna M. Saunders

Appendix 1: Tasmanian and Victorian environmental data

Tasmanian environmental data

Code	Latitude °S	Longitude °E	Silicate µg Si L^{-1}	Phosphate µg P L^{-1}	Nitrate/nitrite µg N L^{-1}	Salinity ppt	pH	Temperature °C	Turbidity NTU	Dissolved oxygen mg L^{-1}
AB1	-41.0625	148.289	306.51	3.79	8.00	31.9	8.08	16.2	2	10.10
AB2	-41.0536	148.27	365.88	67.46	2.28	30.3	7.77	16.1	151	5.60
AB3	-41.0366	148.285	298.04	4.80	1.27	30.0	8.13	15.7	1	10.45
BB1	-42.8466	147.844	48.37	2.59	2.43	33.6	8.11	15.5	0	9.19
BB2	-42.8905	147.809	58.28	1.13	2.19	33.3	8.06	15.6	1	9.40
BB3	-42.8905	147.809	93.29	12.82	52.50	33.7	8.23	17.8	1	11.37
BL1	-41.1847	148.267	639.01	2.96	3.33	11.6	7.10	11.0	8	10.25
CB2	-42.959	147.524	92.98	2.03	4.08	32.7	7.91	13.0	8	5.40
E1	-42.6545	147.939	83.60	2.59	2.19	33.6	7.98	14.4	7	7.90
GB2	-41.2952	148.273	204.95	3.69	6.58	31.4	7.81	12.5	8	7.69
GB3	-41.3112	148.27	161.69	2.65	2.75	32.1	7.91	13.9	0	9.65
GB4	-41.3316	148.248	258.60	7.03	4.90	33.0	7.73	14.0	7	9.90
GB5	-41.3254	148.298	175.09	6.01	5.17	31.8	7.85	13.7	7	9.30
GB6	-41.3035	148.315	151.59	10.13	15.13	32.6	7.46	13.9	5	8.82
GrL1	-41.2539	148.287	320.34	1.55	0.00	29.1	7.88	14.7	5	10.00
GrL3	-41.2535	148.298	445.39	2.17	0.00	27.8	7.67	14.9	29	8.72
GMB1	-40.8324	148.176	731.91	8.52	33.46	14.5	7.94	16.7	11	10.70
GMB2	-40.8361	148.176	236.71	5.65	16.49	20.3	8.22	18.4	5	12.95
GMB3	-40.8399	148.174	390.08	5.23	16.07	18.4	8.11	18.0	6	11.62
He1	-41.4789	148.252	194.00	6.30	9.49	29.6	7.89	14.4	26	9.20
He2	-41.5051	148.269	1132.13	15.43	6.04	23.6	7.85	13.7	10	10.25
LMB1	-40.7657	148.035	286.42	2.20	3.96	29.1	8.26	18.3	1	6.05
LMB2	-40.7659	148.034	292.38	5.00	3.17	27.2	8.12	18.7	0	8.72
LS1	-41.9949	147.989	118.51	4.12	2.87	32.6	7.94	14.2	3	5.95

Code	Latitude	Longitude	Silicate	Phosphate	Nitrate/nitrite	Salinity	pH	Temperature	Turbidity	Dissolved oxygen
	°S	°E	µg Si L^{-1}	µg P L^{-1}	µg N L^{-1}	ppt		°C	NTU	mg L^{-1}
ML1	-41.2678	148.192	274.42	11.63	1.23	29.0	8.22	15.7	2	11.46
ML2	-42.0285	148.221	685.36	11.55	1.16	11.2	7.98	15.9	36	10.15
ML3	-41.9924	148.245	545.84	28.79	0.19	6.5	7.76	15.6	109	7.61
NRL	-43.5	146.25	78.68	6.50	26.89	2.0	7.00	15.7	7.93	6.90
OL1	-42.959	147.524	98.29	7.12	1.06	35.3	8.19	18.2	150	4.06
PC2	-42.959	147.524	45.97	3.62	1.17	33.2	8.02	17.3	3	8.49
SC1	-41.2299	148.282	452.35	15.16	2.03	1.8	7.27	10.4	19	11.15
SL1	-41.2091	148.272	110.78	4.03	12.82	19.4	7.79	11.2	0	10.20
SL2	-41.2043	148.26	304.70	3.75	11.29	4.9	7.29	12.5	14	10.21
SW	-41.4401	148.27	940.90	13.07	0.14	20.2	8.87	15.3	5	12.65
T1	-41.7238	148.272	1068.10	4.71	1.72	28.6	7.75	15.3	23	9.50
W1	-41.4401	148.27	152.67	3.21	19.94	13.8	7.59	13.7	8	10.40
W2	-41.4401	148.27	670.69	4.31	1.17	14.0	7.62	18.1	4	8.96

Victorian environmental data

Code	Latitude	Longitude	Silicate	Phosphate	Nitrate/nitrite	Salinity	pH	Temperature	Turbidity	Dissolved oxygen
	°S	°E	µg Si L^{-1}	µg P L^{-1}	µg N L^{-1}	ppt		°C	NTU	mg L^{-1}
AI1	-38.6734	145.797	1290.96	81.72	389.25	11.4	7.89	17.6	73	4.52
AI2	-38.6614	145.783	864.33	42.78	164.78	23.1	7.84	16.3	16	0.79
AI3	-38.6617	145.77	422.30	19.17	33.12	30.0	7.88	16.8	23	5.42
CI1	-38.7008	146.455	104.55	1.66	2.12	34.3	8.03	17.2	3.5	0.61
CI2	-38.691	146.336	211.59	13.71	0.62	33.8	8.13	17.4	32.5	1.30
CI3	-38.8136	146.267	55.26	1.75	0.57	34.6	8.46	19.0	1.5	1.58
GL1	-37.8788	148.004	270.28	29.92	0.08	24.7	8.13	16.0	1.5	3.44
GL2	-37.8837	147.978	437.71	2.25	0.40	24.6	8.09	15.4	2.5	3.18
GL3	-37.8826	147.975	444.49	2.15	0.04	23.9	8.06	15.7	6	3.33
GL4	-37.8839	147.89	282.24	2.66	0.01	21.7	8.09	15.4	0.5	3.32
GL5	-37.8986	147.855	289.80	6.29	0.02	21.3	8.16	15.5	1.5	3.32
GL6	-37.9276	147.711	550.73	13.98	1.31	20.9	8.07	14.7	0.5	1.53
GL8	-37.8939	147.684	337.54	13.50	0.29	21.4	8.16	16.3	1	3.30
GL10	-37.8876	147.677	1184.42	26.10	13.33	12.0	8.04	16.0	5	3.02
GL11	-37.8823	147.718	1080.08	10.16	14.52	9.6	8.00	15.8	9	3.27
GL12	-37.8823	147.718	474.44	25.52	0.10	20.9	8.14	16.7	4	6.20
LT1	-37.8532	148.084	185.02	11.18	1.86	35.6	7.75	16.4	5.5	2.45
LT2	-37.8529	148.063	149.67	4.63	1.50	36.1	7.65	16.5	18	4.77
LT3	-37.8357	148.074	322.63	2.06	2.40	35.8	7.69	16.3	1.5	4.03
LT4	-37.8123	148.057	465.66	11.97	0.36	27.7	7.64	17.5	6	4.50
MC1	-37.5099	149.692	842.00	2.69	0.16	25.6	7.81	16.5	8	5.53
MC2	-37.4993	149.702	569.63	5.22	2.58	25.3	7.84	16.9	7	6.91
MC3	-37.5327	149.74	242.19	3.31	0 85	24.7	7.93	15.7	3	6.00
MC4	-37.5367	149.742	137.17	4.14	2.04	25.8	7.98	15.7	6	6.71
MC5	-37.511	149.702	469.13	1.35	0.02	26.2	7.91	16.8	1.5	5.33

Code	Latitude	Longitude	Silicate	Phosphate	Nitrate/nitrite	Salinity	pH	Temperature	Turbidity	Dissolved oxygen
	°S	°E	µg Si L^{-1}	µg P L^{-1}	µg N L^{-1}	ppt		°C	NTU	mg L^{-1}
P3	-37.86	144.866	183.38	68.33	28.25	33.0	7.63	9.6	6	2.99
P4	-37.8639	144.838	973.33	100.57	434.17	0.8	8.39	16.3	139.665	2.22
P5	-37.8746	144.817	84.72	264.43	1.55	34.1	8.00	16.9	12.5	1.64
P6	-37.9543	144.721	304.65	199.27	696.14	33.7	7.97	17.1	47	1.41
P7	-37.9718	144.699	264.62	195.11	586.14	34.2	8.01	17.3	36.5	1.42
P9	-38.0292	144.563	154.45	347.61	25.04	34.7	8.05	19.0	10	1.60
P10	-38.0865	144.424	148.63	140.13	0.95	36.5	8.22	19.2	7.25	1.85
P12	-38.1599	144.455	261.99	64.33	4.76	35.6	8.11	17.0	2	7.71
P13	-38.1164	144.671	62.48	48.85	1.93	34.9	7.96	15.0	0	6.03
P14	-38.1616	144.714	225.53	161.75	4.31	40.0	8.05	11.8	131	11.93
P15	-38.369	144.858	258.69	55.97	1.94	33.7	7.92	17.0	1	7.77
P16	-38.0992	144.782	331.19	59.10	97.35	33.5	7.67	13.8	2	18.90
P17	-38.0864	145.463	418.99	55.60	189.33	31.1	7.94	17.0	5	9.58
SI2	-38.8423	146.151	86.14	16.91	4.71	33.9	7.92	15.6	24.5	5.57
SYD1	-37.7625	148.971	355.30	3.79	6.35	16.4	7.63	15.6	14	9.77
TAM1	-37.7434	149.136	891.70	5.87	1.08	19.0	7.46	15.1	10	8.46
WPB1	-38.4094	145.419	274.37	1.55	7.19	33.3	7.90	17.5	7.5	5.31
WPB2	-38.3082	145.52	835.57	11.83	71.01	32.0	7.76	18.0	44.5	4.52
WPB3	-38.217	145.376	461.25	4.74	57.04	32.1	7.79	18.9	22.5	6.44
WPB4	-38.3755	145.221	84.24	0.00	0.00	34.0	7.68	12.4	9	14.98

Appendix 2: Tasmanian and Victorian diatom species list and raw data

- Tasmanian and Victorian diatom species list ordered by scientific name
- Tasmanian and Victorian diatom species list ordered by code
- Tasmanian diatom species occurrences
- Victorian diatom species occurrences

Species list ordered by scientific name

Species name	Code
Achnanthes angustata	OPE6
Achnanthes brevipes var. *angustata*	EPI1a
Achnanthes brevipes var. *intermedia*	EPI1
Achnanthes cf. *amoena*	ACHres
Achnanthes hungarica	ACH2
Achnanthes sp. 1	PLAhau3
Achnanthes sp. 2	ACH17
Achnanthes sp. 3	PLApol3
Achnanthes yarrensis	ACH6
Actinocyclus senarius	GRAarc
Actinocyclus sp. 1	CEN7
Actinocyclus subtilis	CEN10
Amphora acutiuscula	AMPcof
Amphora caroliniana	AMPcof3
Amphora cf. *bisecta*	AMPlae1a
Amphora cf. *kolbei*	AMPlae1
Amphora cf. *laevissima*	AMPlae
Amphora cf. *luciae*	AMP18
Amphora copulata	AMP11
Amphora costata	AMP9
Amphora decussata	AMPlae5
Amphora eunotia	AMP15
Amphora exigua	AMPcof2
Amphora sp. 1	AMP3
Amphora sp. 2	AMP14a
Amphora sp. 3	ACH6a
Amphora sp. 4	AMP7
Amphora sp. 5	UNK4
Anorthoneis vortex	VIK10
Ardisonnia formosa	ARDfor
Aulacoseira pfaffiana	CEN9a
Bacillaria paxillifer	NITscal
Berkeleya sp. 1	BER1
Biremis lucens	UNK7
Biremis sp. 1	BRF1
Caloneis elongata	NAV43
Catenula adherens	AMP1
Chamaepinnularia cf. *clamans*	UNK19c
Cocconeis costata	COCcos
Cocconeis krammeri	COChet
Cocconeis molesta var. *crucifera*	COCmol
Cocconeis neodiminuta	rVIK5
Cocconeis pediculus	COC4a
Cocconeis pediculus var. 1	COC4
Cocconeis pellucida	COCpel

Species name	Code
Cocconeis peltoides	ACH3
Cocconeis placentula	COCpla
Cocconeis placentula	VIKpro
Cocconeis placentula var. *euglypta*	COCplae
Cocconeis pseudomarginata	COCpse
Cocconeis scutellum	COCscu
Cocconeis scutellum var. 1	COCdis
Cocconeis scutellum var. *parva*	COCscup
Cocconeis sp. 1	UNK107
Coscinodiscus centralis	CEN1
Coscinodiscus nitidis	CEN9
Cosmioneis cf. *pusilla*	NAV2
Cyclotella choctawhatceeana	CYCstr2
Cyclotella meninghiana	CEN15
Cyclotella striata	CYCstr
Cymbella sp. 1	CYMasp
Cymbella sp. 2	CYMasp3
Delphineis sp. 1	VIK7
Dephineis minutissima	ACHpse
Diatomella cf. *balfouriana*	UNK37b
Dimeregramma minor var. *nana*	VIK3
Diploneis cf. *decipens* var. *parallela*	DIPnot
Diploneis cf. *domblitlensis*	FAL2
Diploneis cf. *litoralis*	DIP5
Diploneis cf. *marginestriata*	DIP9
Diploneis sp. 1	DIPnot2
Diploneis stroemii	DIP8
Entomoneis alata	UNK102
Entomoneis kjellmanii	UNK102a
Epithema zebra	EPIzeb
Fallacia cf. *versicolor*	FAL4
Fallacia florinae	DIPvac
Fallacia psuedony	FAL5
Fallacia sp. 1	COC14
Fallacia subforcipata	FALsub
Fallacia tenera	FAL8
Fragilaria capucina	FRA8
Fragilaria cf. *bilunaris*	FRA7
Fragilaria cf. *geocollegarum*	FRAgeo
Fragilaria cf. *schulzii*	FRAshu
Fragilaria ellipta	CEN5
Fragilaria ellipta agg.	UNK80
Fragilaria pinnata	SYN3
Fragilaria pulchella	UNK69a
Grammatophora angulosa var. *angulosa*	GRA3
Grammatophora macilenta	GRAmac

Species name	Code
Grammatophora marina	GRAoce
Grammatophora oceanica	GRAmar
Grammatophora subtilissima	GRAsub
Gyrosigma balticum	GYRattl
Hanzschia sp. 1	EUN1
Hanzschia sp. 2	NIT11a
Huttoniella reicardtii	CEN2
Licmophora cf. *debilis*	LIC1
Licmophora sp. 1	LIC1a
Lunella cf. *bisecta*	AMPlae2
Lyrella amphoroides	FAL11
Martyana cf. *schulzii*	FRA3
Mastogloia baldjkiana	MAS2
Mastogloia exilis	MAS4b
Mastogloia lanceolata	ACH11
Mastogloia macdonaldii	MAS3
Mastogloia parva	MAS6
Mastogloia pumila	MAS5
Mastogloia pusilla	MAS2a
Melosira lineata var. *juergensis*	UNK43
Melosira nummuloides	MEL1
Microtabella interrupta	GRA2
Navicula cf. *leptoloba*	NAV12
Navicula cf. *libonensis*	NAV14
Navicula cf. *lusoria*	ACH14
Navicula cf. *ramosissima* var. *torquata*	PLApol2
Navicula cf. *salinarum*	NAV4
Navicula cf. *salinarum* var. 1	NAVryn
Navicula cf. *syvertsenii*	NAV16
Navicula digitoradiata	NAVvir3
Navicula marina	COC9
Navicula perminuta	NAVper
Navicula perminuta var. 1	UNK1
Navicula recens	NAV1
Navicula recens var. 1	NAV10
Navicula salinarum var. *salinarum*	NAV3
Navicula sp. 1	UNK30
Navicula sp. 2	ACH15
Navicula sp. 3	NAV42
Navicula sp. 4	NAV19
Navicula sp. 5	NAV30
Navicula sp. 6	NAV36
Navicula sp. 7	UNK126
Nitzschia cf. *distans*	NIT10
Nitzschia cf. *valdestriata*	NITval
Nitzschia compressa	FRAvir

Species name	Code
Nitzschia didyma	NITpan
Nitzschia lanceola	NITlan
Nitzschia sp. 1	NIT6
Nitzschia sp. 2	NIT6a
Odontella sp. 1	UNK24
Opephora guenter grassii	OPEgue
Opephora pacifica	OPEbur/OPEbur2
Paralia sp. 1	PARsul
Plagiogramma sp. 1	UNK69
Plagiotropsis sp. 1	UNK200
Planothidium cf. *lanceolata*	ACHres3
Planothidium delicatulum	PLAdel
Planothidium delicatulum var. 1	PLAdel3
Planothidium delicatulum var. 2	PLAdel4
Planothidium delicatulum var. 3	FRA1
Planothidium dispar	PLAdis
Planothidium hauckianium	PLAhau
Planothidium hauckianium var. 1	PLAhau2
Planothidium quarnerensis	UNK19
Pleurosigma cf. *salinarum*	GYRbal
Pseudostaurosira perminuta	PSEper
Rhopalodia acuminata	RHA3
Rhopalodia brevosonnia	RHA2
Seminavis sp. 1	STA2
Stauroneis sp. 1	UNK87a
Synedra sp. 1	SYNcam
Synedra sp. 2	SYN1
Synedra sp. 3	UNK14
Synedra ulna	UNK100c
Tabularia fasciculata agg.	SYNfas
Tabularia sp. 1	UNK28
Trachyspenia australis var. *australis*	VIK8a
Tryblionella coarctata	NITpan1
Unknown sp. 1	AMP6b
Unknown sp. 10	NAV34
Unknown sp. 11	NAV44
Unknown sp. 12	NAV7b
Unknown sp. 13	NAVvir
Unknown sp. 14	NIT2
Unknown sp. 15	UNK116a
Unknown sp. 2	NAV32a
Unknown sp. 3	STA4
Unknown sp. 4	UNK111
Unknown sp. 5	UNK117
Unknown sp. 6	UNK31a
Unknown sp. 7	UNK64
Unknown sp. 8	ACH22

Species name	Code
Unknown sp. 9	COCpla1

Species list ordered by code

Species name	Code
Mastogloia lanceolata	ACH11
Navicula cf. *lusoria*	ACH14
Navicula sp. 2	ACH15
Achnanthes sp. 2	ACH17
Achnanthes hungarica	ACH2
Unknown sp. 8	ACH22
Cocconeis peltoides	ACH3
Achnanthes yarrensis	ACH6
Amphora sp. 3	ACH6a
Dephineis minutissima	ACHpse
Achnanthes cf. *amoena*	ACHres
Planothidium cf. *lanceolata*	ACHres3
Catenula adherens	AMP1
Amphora copulata	AMP11
Amphora sp. 2	AMP14a
Amphora eunotia	AMP15
Amphora cf. *luciae*	AMP18
Amphora sp. 1	AMP3
Unknown sp. 1	AMP6b
Amphora sp. 4	AMP7
Amphora costata	AMP9
Amphora acutiuscula	AMPcof
Amphora exigua	AMPcof2
Amphora caroliniana	AMPcof3
Amphora cf. *laevissima*	AMPlae
Amphora cf. *kolbei*	AMPlae1
Amphora cf. *bisecta*	AMPlae1a
Lunella cf. *bisecta*	AMPlae2
Amphora decussata	AMPlae5
Ardisonnia formosa	ARDfor
Berkeleya sp. 1	BER1
Biremis sp. 1	BRF1
Coscinodiscus centralis	CEN1
Actinocyclus subtilis	CEN10
Cyclotella meninghiana	CEN15
Huttoniella reicardtii	CEN2
Fragilaria ellipta	CEN5
Actinocyclus sp. 1	CEN7

Species name	Code
Coscinodiscus nitidis	CEN9
Aulacoseira pfaffiana	CEN9a
Fallacia sp. 1	COC14
Cocconeis pediculus var. 1	COC4
Cocconeis pediculus	COC4a
Navicula marina	COC9
Cocconeis costata	COCcos
Cocconeis scutellum var. 1	COCdis
Cocconeis krammeri	COChet
Cocconeis molesta var. *crucifera*	COCmol
Cocconeis pellucida	COCpel
Cocconeis placentula	COCpla
Unknown sp. 9	COCpla1
Cocconeis placentula var. *euglypta*	COCplae
Cocconeis pseudomarginata	COCpse
Cocconeis scutellum	COCscu
Cocconeis scutellum var. *parva*	COCscup
Cyclotella striata	CYCstr
Cyclotella choctawhatceeana	CYCstr2
Cymbella sp. 1	CYMasp
Cymbella sp. 2	CYMasp3
Diploneis cf. *litoralis*	DIP5
Diploneis stroemii	DIP8
Diploneis cf. *marginestriata*	DIP9
Diploneis cf. *decipens* var. *parallela*	DIPnot
Diploneis sp. 1	DIPnot2
Fallacia florinae	DIPvac
Achnanthes brevipes var. *intermedia*	EPI1
Achnanthes brevipes var. *angustata*	EPI1a
Epithema zebra	EPIzeb
Hanzschia sp. 1	EUN1
Lyrella amphoroides	FAL11
Diploneis cf. *domblitlensis*	FAL2
Fallacia cf. *versicolor*	FAL4
Fallacia psuedony	FAL5
Fallacia tenera	FAL8
Fallacia subforcipata	FALsub
Planothidium delicatulum var. 3	FRA1
Martyana cf. *schulzii*	FRA3
Fragilaria cf. *bilunaris*	FRA7
Fragilaria capucina	FRA8
Fragilaria cf. *geocollegarum*	FRAgeo
Fragilaria cf. *schulzii*	FRAshu
Nitzschia compressa	FRAvir
Microtabella interrupta	GRA2
Grammatophora angulosa var. *angulosa*	GRA3

Species name	Code
Actinocyclus senarius	GRAarc
Grammatophora macilenta	GRAmac
Grammatophora oceanica	GRAmar
Grammatophora marina	GRAoce
Grammatophora subtilissima	GRAsub
Gyrosigma balticum	GYRattl
Pleurosigma cf. *salinarum*	GYRbal
Licmophora cf. *debilis*	LIC1
Licmophora sp. 1	LIC1a
Mastogloia baldjkiana	MAS2
Mastogloia pusilla	MAS2a
Mastogloia macdonaldii	MAS3
Mastogloia exilis	MAS4b
Mastogloia pumila	MAS5
Mastogloia parva	MAS6
Melosira nummuloides	MEL1
Navicula recens	NAV1
Navicula recens var. 1	NAV10
Navicula cf. *leptoloba*	NAV12
Navicula cf. *libonensis*	NAV14
Navicula cf. *syvertsenii*	NAV16
Navicula sp. 4	NAV19
Cosmioneis cf. *pusilla*	NAV2
Navicula salinarum var. *salinarum*	NAV3
Navicula sp. 5	NAV30
Unknown sp. 2	NAV32a
Unknown sp. 10	NAV34
Navicula sp. 6	NAV36
Navicula cf. *salinarum*	NAV4
Navicula sp. 3	NAV42
Caloneis elongata	NAV43
Unknown sp. 11	NAV44
Unknown sp. 12	NAV7b
Navicula perminuta	NAVper
Navicula cf. *salinarum* var. 1	NAVryn
Unknown sp. 13	NAVvir
Navicula digitoradiata	NAVvir3
Nitzschia cf. *distans*	NIT10
Hanzschia sp. 2	NIT11a
Unknown sp. 14	NIT2
Nitzschia sp. 1	NIT6
Nitzschia sp. 2	NIT6a
Nitzschia lanceola	NITlan
Nitzschia didyma	NITpan
Tryblionella coarctata	NITpan1
Bacillaria paxillifer	NITscal
Nitzschia cf. *valdestriata*	NITval

Species name	Code
Achnanthes angustata	OPE3
Achnanthes angustata	OPE6
Opephora pacifica	OPEbur/OPEbur2
Opephora guenter grassii	OPEgue
Paralia sp. 1	PARsul
Planothidium delicatulum	PLAdel
Planothidium delicatulum var. 1	PLAdel3
Planothidium delicatulum var. 2	PLAdel4
Planothidium dispar	PLAdis
Planothidium hauckianum	PLAhau
Planothidium hauckianium var. 1	PLAhau2
Achnanthes sp. 1	PLAhau3
Navicula cf. *ramosissima* var. *torquata*	PLApol2
Achnanthes sp. 3	PLApol3
Pseudostaurosira perminuta	PSEper
Rhopalodia brevosonnia	RHA2
Rhopalodia acuminata	RHA3
Cocconeis neodiminuta	rVIK5
Seminavis sp. 1	STA2
Unknown sp. 3	STA4
Synedra sp. 2	SYN1
Fragilaria pinnata	SYN3
Synedra sp. 1	SYNcam
Tabularia fasciculata agg.	SYNfas
Navicula perminuta var. 1	UNK1
Synedra ulna	UNK100c
Entomoneis alata	UNK102
Entomoneis kjellmanii	UNK102a
Cocconeis sp. 1	UNK107
Unknown sp. 4	UNK111
Unknown sp. 15	UNK116a
Unknown sp. 5	UNK117
Navicula sp. 7	UNK126
Synedra sp. 3	UNK14
Planothidium quarnerensis	UNK19
Chamaepinnularia cf. *clamans*	UNK19c
Plagiotropsis sp. 1	UNK200
Odontella sp. 1	UNK24
Tabularia sp. 1	UNK28
Navicula sp. 1	UNK30
Unknown sp. 6	UNK31a
Diatomella cf. *balfouriana*	UNK37b
Amphora sp. 5	UNK4
Melosira lineata var. *juergensis*	UNK43
Unknown sp. 7	UNK64
Plagiogramma sp. 1	UNK69

Species name	Code
Fragilaria pulchella	UNK69a
Biremis lucens	UNK7
Fragilaria ellipta agg.	UNK80
Stauroneis sp. 1	UNK87a
Anorthoneis vortex	VIK10
Dimeregramma minor var. *nana*	VIK3
Delphineis sp. 1	VIK7
Trachyspenia australis var. *australis*	VIK8a
Cocconeis placentula	VIKpro

Code	AB1	AB2	AB3	BB1	BB2	BB3	BL	CB2	E1	GB2	GB3	GB4	GB5	GB6	GrL1	GrL3	GMB1	GMB2	GMB3	He1	He2	LMB1	LMB2
ACH14	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	2.00	0.00	0.00	5 61	0 00	0.00	0.00	0.00	0 00	0.00	0.00	1 50	0.00
ACH15	0 00	0 00	0 00	2 48	0.00	0.00	0 00	1 75	0.00	0 00	0.00	0.00	0.72	0 24	0.00	0.00	0.00	0.00	0.00	0.00	0.25	1.25	0.00
ACH17	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	1.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00
ACH2	0 00	0.00	0 00	0.00	0.00	0.00	0.00	2 99	0 00	0 00	0 00	0 51	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ACH22	0.00	0 00	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	1.00	1.27	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0.00
ACH3	4 59	0.00	10 35	0.99	1.52	0.00	1 24	1 75	0 00	1 25	0 25	0.00	0.72	2.68	13 11	0.00	2.98	5.24	2.50	0.00	0.75	3 00	2.76
ACH6	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0.51	0.00	0.00	0.00	0.00	0.00	0.00	1.75	0.00	0 00	0 00	0 00
ACH6a	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	2.00	0 75	5 32	0 00	0 00	0 00	0 00	0 74	1 75	0 75	0 23	3 50	0 00	0 00
ACHbre3	0 00	0.00	0.00	0 00	0.00	0 00	0.00	0.75	0 00	0.25	0 00	0.25	0.00	0.49	0.00	0.00	0 25	0.00	0.50	0.00	0 00	1.25	0.75
ACHpse	0 48	0 48	0 00	0 00	0 25	0.00	0.25	0 00	0 00	0.00	1.25	4.30	1.19	0.00	0 00	0 00	0 00	0 00	0.00	0.00	1.75	0.25	0.50
ACHres	0.72	0 24	0 47	0.00	1.77	0 23	0 25	0 00	0.00	0 00	0 50	2 03	1 67	0.24	0 98	0 87	0 00	0.25	0 25	0 23	4 50	0 00	0 00
AMP1	10 87	0.24	9 41	0 00	5 32	0.69	1.49	1 75	6 16	5 50	1.75	1.52	1.91	0 00	5.57	1 74	5.96	15.46	15.25	13.04	3.50	0.00	0.25
AMP11	2.42	0 00	1 41	9 90	2 03	0.00	1 00	0 00	2 22	4 75	0 00	0 51	3.58	3.41	0 33	0.00	0.00	0.00	0.50	0.92	0.00	0.50	1 50
AMP14a	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0 25	0 00	1.01	7.88	1 46	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0 00	0.00
AMP15	0 00	0.24	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0.25	0.00	0.00	0.48	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0.50
AMP18	0 00	0.24	0 00	0 00	0.00	0.46	1 24	0 75	3 69	0.00	0.00	0.00	0 00	0.00	0.98	2.61	0.00	0.00	0 00	0 00	0 00	0.00	0 00
AMP3	0 00	0.00	0 00	0 00	0 00	0.00	3.48	0 00	0 00	0.00	0.25	0.76	1.67	0.00	0.00	3.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AMP6b	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0.00	0 00	0.00	0 00	0 00	0 00
AMP9	2.17	0 00	1 41	3 47	3 04	0 92	0 75	0 50	2.71	2 50	0 00	0.00	1.19	1 95	0.00	9.57	0.25	2.24	0 25	0.46	0 00	0 50	0.00
AMPcof	1.45	0 24	0.71	8.91	1.01	0 00	8 46	0 75	2.46	1.50	3.25	3.80	0.95	3 66	2 30	12 17	6.70	4.24	0.75	2.97	2.75	4.75	4.01
AMPcof2	0.00	0 00	0.00	7.43	0.00	0 00	0 25	0 00	0.25	0.25	1 50	1 52	0 95	1 46	2 62	0 00	1 49	1 00	0 00	1 60	1 75	4 25	2 26
AMPlae	1.69	0 00	0.00	0 99	0.00	0 00	0 00	1 25	0.00	0.00	0.25	4.05	0.72	0 49	1 64	3 48	0.50	0.00	0.00	0.00	2.25	0.00	0.50
AMPlae2	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0.00	0.00	1.75	0.00	0 00	0 00	4 88	0 00	0 00	0.99	0 00	0 00	0.00	0.00	0.25	1.25
AMPlae5	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	1 97	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00
ARDfor	0 00	0 00	0 00	0.00	0 51	0.00	0.00	0 25	0.00	0.75	0.00	0 00	0 00	0.00	0 00	1 74	0.00	0.00	0 75	0 46	0.00	0.00	0.00
BER1	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0.24	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0 00
BRF1	1.93	0.00	0 00	0 00	1 01	0.00	0.00	0 75	0 00	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0 00	0 50	0 00	0 00	0 00	0 00	0.00
CEN1	0.00	2 39	0.24	0.00	0 25	0.00	1 49	4 24	0.00	0.50	0 00	0 00	0 24	3.41	0 00	0.00	0.25	0.25	1.50	0.00	0 00	1 25	0.50
CEN10	0 24	0 00	0.00	0 50	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0.00
CEN15	0.00	3 83	0.71	0 00	2.78	0 00	0 50	3.74	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0 00	0 00	0 25	0 00	0.25	0.00	0 00
CEN5	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0 25	1.00	0 00	0 00	0 49	0 00	0 00	0 74	1 50	0.50	0 00	0 00	11 50	5 26
CEN9	0 00	0.00	0.94	0 00	0 25	0.00	0 00	2.74	0 00	0 00	0.00	0 00	0 24	0 49	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00
CEN9a	2 42	0 00	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.50	0.00	0 00
COC14	0.00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00
COC4	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0 00

Code	AB1	AB2	AB3	BB1	BB2	BB3	BL	CB2	E1	GB2	GB3	GB4	GB5	GB6	GrL1	GrL3	GMB1	GMB2	GMB3	He1	He2	LMB1	LMB2
COC4a	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00
COC9	0.97	0.00	0 24	0 00	0 00	0 00	0 00	1 25	1.72	0.00	0.00	0.00	0.00	0.24	0.33	0.00	0.00	0.00	0.00	0.23	0.00	0 00	0 00
COCcos	0 00	0 24	0 24	0 00	0.00	0 00	0 00	1 25	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0.00
COCdis	0.24	3 59	0.24	0 00	1 52	0 00	2.49	0.75	0.00	2.75	0.75	0 00	0.95	3 90	0.00	0.00	2.98	0 75	2 75	0.23	0.00	4 00	8 27
COCpla	15 46	0 00	6.12	0.99	5.32	1.38	9 70	6.48	0 00	0.50	0 75	0.00	0.00	0.24	0 98	2 61	6 95	8 48	10.50	1.60	0 25	5.25	5.01
COCplae	0.00	0 00	0 00	0 00	0 00	0 00	0 00	1.25	0.00	0.25	0.25	0 00	0 00	0 00	0 98	0.00	3.72	2.00	2 50	0.46	0.25	0 00	0 00
COCscu	1.93	11.96	0 71	0 00	0 25	0.23	20.15	0.25	0.00	0.25	0.25	0.51	1.43	0 49	0 00	0.00	2.23	0 75	1 75	7.32	1.00	0 25	0 00
COCscup	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 25	0.25	0 00	1 22	0.00	0.00	0 00	0.50	0 00	0.00	0.00	2 25	1 00
CYCstr	0.00	0 00	0.00	0.00	0 00	0 69	4 48	0 00	0 00	0 00	0 00	0 00	0.00	0 00	1.97	6.09	0.00	0.00	0 00	0.00	0.00	0 00	0 00
CYCstr2	0.97	0 48	0.24	0.50	1 77	0 00	6 97	2.00	2 71	0 50	0 00	0 00	0.00	0 00	0 00	0 87	0.50	0 50	1 00	5.03	0 25	0.00	0.25
CYMasp3	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0.00
DIP5	2.42	0.00	0.24	1.49	0 00	0.00	0.00	2.49	5.17	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0.69	0 00	0 00	0 00
DIP8	0 48	0 00	0 00	0.00	0 25	0.00	0.00	0.00	8.62	0 00	1.75	0.25	0 24	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0 00	0 00
DIPnot	0.00	0.00	0.00	0 00	0 51	0 00	0 25	0 25	1.23	0 00	0 00	0 00	0.24	0 00	0.98	0 00	0.00	0 25	0 00	0 00	0.00	0.00	0.00
EPI1	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0 00	0.25	0 51	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0.00
EPI1a	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 25	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0 00
FAL11	0 48	0 00	0.00	2 48	0 00	0 00	0 00	2 00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00
FAL2	0 00	0.00	0.00	0.50	0 25	0 00	0.00	0.00	0 00	0 00	0 75	0 25	0.00	14.88	0.00	0 00	0 74	1 75	0.00	0 00	0 25	0 00	0.00
FAL4	0.00	0 00	0.00	0 00	0 00	0 00	0 00	2 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00
FAL5	0.72	0 00	1 65	0 00	2 03	0 00	0 00	0 00	0.00	0 50	0 00	3 80	2 39	0 24	7.54	0.87	0 00	0 00	0 25	0.92	1.00	0 00	0 00
FRA1	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 25	0.00	0 00	0.00	0.00	0 25	1 00	0.00	0.00	0 00	2 75	2 01
FRA3	1 93	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0 00
FRA7	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0 00
FRAgeo	0 00	0 00	0 24	0 00	1.27	0 92	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0.87	0 00	0.00	0.00	0.00	0 00	0.00	0.25
FRAvir	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0 00	0.23	0 00	0 00	0.00
GRA2	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0.75	1 25	0.00	0.00	0 00	0 00
GRA3	0.00	0.00	1.41	0.00	0 00	0.00	0.00	1.25	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0.25	0.00	0 00	0 00	0.00	0.00	0 00
GRAmac	0.48	1.20	2.82	0.00	0.00	0.00	0.00	0.00	0 00	0.25	0.00	0.00	0 24	0 24	0.00	0.00	0.00	0.25	0 00	0.00	0.00	0 00	0 00
GRAmar	0 00	2.39	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.50	0.00	0.00	0 00	0.00	0.00	0.50	0 00	3.75	0.00	0 00	0.00	0.00
GRAoce	7 49	41 87	14.59	0 00	0.00	0 00	0 00	0 00	0 00	0 00	1 25	0.00	0.48	0 49	0.33	0.00	0.50	0.00	0 75	0 23	0.00	0.50	0 00
GRAsub	0 00	5 98	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 98	0 00	0.00	0.50	0.00	0.00	0 00	0.00	0 00	0 00
GYRatt1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0 00
GYRbal	0 97	0 24	0 00	0.00	0 25	0 00	0.25	2 49	0.00	0.75	0 25	0.25	0 00	0 00	0.00	0.87	0 74	0.00	0 00	0.69	0 75	0.25	0 50
MAS2	0 00	1.91	0 94	0.00	0 00	0.00	0.00	0 00	0 49	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0 00
MAS2a	0 00	0.00	1.41	0.00	0.00	0.00	0.00	0.00	24 88	0.00	1.00	0 25	0.00	0 00	1 97	0.87	0.00	0 00	0 00	0.23	0.00	0 00	0 00
MAS3	0.00	2.15	0.24	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0 00	0 33	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0 00

Code	AB1	AB2	AB3	BB1	BB2	BB3	BL	CB2	E1	GB2	GB3	GB4	GB5	GB6	GrL1	GrL3	GMB1	GMB2	GMB3	He1	He2	LMB1	LMB2
NAV1	2.17	1.67	0.71	1.49	1.77	0.92	0.50	7.48	3.45	1.25	2.50	0 76	0.95	0 24	1.31	6.96	0.50	1 00	1 00	1.14	8 75	1 75	1.25
NAV10	0.00	0 00	0 00	0.00	0.00	0 00	0 75	0.00	8.87	0.50	0.25	2.03	0.00	0.00	3.28	0.00	0.50	0 75	0 00	1.37	0.00	1 00	2.01
NAV2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	2.00	0 00	0.24	0 00	0.00	0.00	0 25	0 00	0.00	0.23	0 00	0.00	0.00
NAV3	1.93	1 44	0 24	0 00	1.52	11 47	0 75	0 25	0 49	2.75	9.00	6.08	2.39	0 49	0.98	0.87	0.25	0.25	0 00	1.83	5 50	2 25	0.50
NAV30	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0 00	0.00
NAV32a	0 00	0.00	0 00	0.00	0.00	0.00	1 24	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.87	0.00	0 00	0 00	0.00	0 00	0 00	0.00
NAV4	0.24	0.00	0 47	0 50	0.00	0.00	0 00	0 75	0 99	1 75	4 50	6.84	1.67	1 95	0.00	0 87	1 74	0.25	0 00	0 00	4 00	1.00	0.25
NAV42	0 00	0.00	0.00	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0.00
NAV43	1 21	0 00	0 24	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0 00
NAV44	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0.00
NAV7b	0 00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0.00
NAVper	0 24	0.00	0.47	0.00	1 27	0.69	1 24	0 75	14.29	5 00	3.75	1 27	2.15	2.44	2.62	1.74	5.46	2.99	0 50	2.97	2 75	5 50	4.51
NAVryn	0 00	0.00	0.47	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	1 43	0.00	0.00	0.00	0.00	0.25	0 25	0.00	0 00	1.25	0 50
NAVvir	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0.33	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0 00
NAVvir3	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0 00
NIT10	0.00	0.00	0.00	0.00	1 01	0.00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	2 25	0 00	0 00
NIT6	0.97	0.24	0.24	0.99	0.25	0.00	0.00	0.00	0 00	0 00	0.00	0.51	0.00	0 00	0 00	2 61	0 00	0.25	0 00	0.00	2 75	1.50	0.25
NIT6a	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0 25	0 00	0 00	0 00	0.00	0 50	0.50	0.00	0 00	0 00	3.75	1 25
NITpan1	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0 25	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0.00	1.50	0 25
NITscal	0 48	0 48	0 24	0 00	0 25	0 00	0 00	0.50	0.74	1 75	3.50	0.25	0 00	0 00	0.33	0.00	0 25	0 50	0.75	0 69	0.25	0.00	0 50
NITval	0.00	0 48	0.47	14.85	0.00	0.00	0.75	0 25	0.00	0 00	1 50	1.27	1.43	0.49	2 30	4 35	0 00	0 75	0.00	0 92	0.00	3 75	6.77
OPE3	0 00	0 00	0 94	0 00	0.76	0 46	2 24	0.00	0.00	0 75	0.00	0 51	0.72	0 73	0.00	0.00	17 12	1.50	0.50	0 00	7.00	8.75	3 51
OPE6	0 24	0 00	3 76	1 49	0 00	1 38	0 25	0 00	0 00	2.25	1.25	0.76	0 24	5 37	0 00	0.00	3 23	6.48	0.75	0 00	0 00	5 00	5 51
OPEbur	3 62	0 72	9 41	17 33	16 46	64.22	0 75	0 00	0.00	1.50	3.25	3.54	5 01	5 61	12.13	3.48	7 20	7 23	5.25	2 06	15 75	2.75	9 52
OPEbur2	0.00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	20.29	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0.00
OPEgue	0.72	0.24	1 88	3.47	7 85	8.03	0 00	0.75	0.00	1 50	2 50	1.77	1.67	2.20	9.18	8 70	4 47	5.49	2.75	6 41	2.50	5.25	7 27
PARsul	0 00	0.48	0 00	0 00	0.00	0.00	0 00	1 25	0 00	2 75	4.75	4.56	0 00	0 73	2.30	4.35	1.24	0 00	0.50	1 83	1 25	0.00	0 00
PLAdel	0 97	0 00	1 88	5 45	2.28	0 92	1 99	2 99	0 25	2.50	10.00	7.85	5.01	0 24	0 98	0.00	3.23	2 99	6.00	5.26	6 00	1.00	2.51
PLAdel3	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	3 00	3.50	1 01	0.00	0 24	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0 25
PLAdel4	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0 00	0 00	1 25	0.00	0.25	0.48	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0.00
PLAhau	15.94	0.48	1.18	9.90	23 04	0.46	5.22	29.18	0.74	12.25	5.00	9 87	5 97	8.29	6 56	3 48	6.70	12.22	13 75	7.55	6.00	1 75	8.02
PLAhau3	2.42	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 25	1 25	3.50	2.03	1.19	0.49	0 00	0.00	0.00	0.25	0 00	21.97	0 00	0.50	1.50
PLApol3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0.00
PSEper	0.00	1 44	0 00	0 00	1 27	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0 00
RHA2	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	1.37	0 00	0.00	0 00

Code	AB1	AB2	AB3	BB1	BB2	BB3	BL	CB2	E1	GB2	GB3	GB4	GB5	GB6	GrL1	GrL3	GMB1	GMB2	GMB3	He1	He2	LMB1	LMB2
RHA3	0.00	3.35	0.47	0.00	0 25	0 00	1.00	0 00	0.74	1.50	0.00	0 25	0 72	0.00	0 33	4.35	0.25	0.00	0.50	1 60	2.00	0.25	0 00
rVIK5	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0 25	0 00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.25	0.25	0.00	0.00	0 00	0 00
STA2	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	2 71	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0 00	0 00	0.69	0.00	0.00	0 00
SYN1	0.00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0.25	0.00	0.00	0.24	0.00	0.00	0.00	0 00	3 00	0.00	0.00	0.00	0.00
SYNcam	0 00	0 24	0.24	0.00	0.00	1 38	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 75	0 25	0.00	1 50	0.00	1.50
SYNfas	0.00	0.24	0 00	0.00	0.00	0.23	0.25	0.00	0 00	1 25	0 75	0 51	0 00	0.24	0.00	0.00	0.50	1.25	4 75	0.23	0.00	0.00	0 00
UNK100c	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0.25	0.00	0.00	0 24	0.00	0.00	0.00	0.00	0 00	0.00	0.00	1.25	0 00
UNK102	0.24	0 00	0 00	0 99	0.00	0.00	0.00	2.24	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0.87	0 00	0 00	0.00	0.00	1.00	0.50	0.50
UNK102a	1.21	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00
UNK107	0.00	0 00	0 00	0 00	4 30	0.00	0.00	0.00	1.48	8 75	4 75	0.00	0 00	1 22	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00
UNK117	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0 00	0.00
UNK126	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	9.07	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00
UNK19	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	4.00	1.50	0.51	0.00	0.00	0.00	0.00	0 74	0.00	0.00	0 00	0.00	0.75	0.25
UNK19c	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	1 64	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00
UNK200	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	1 74	0 00	0 00	0.00	0.00	0.00	0.00	0.00
UNK24	0.24	0 00	0.00	0 00	1 01	0 92	0.00	0.00	0.00	1.25	0.75	0.51	0.00	0 49	0.00	0 00	0 00	0.25	0.00	0.00	0.00	0.00	0.00
UNK28	0.00	0.00	1.18	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00
UNK30	0 97	0 00	2.82	0.00	0.76	0.46	0.25	1.75	0.74	3.25	3.00	1 77	0 00	0.49	0.98	0.00	1 24	0 00	1.75	0 00	0.50	0.50	0.75
UNK37b	0 00	0.00	0.00	0.00	0 00	0 00	12 94	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0.00
UNK43	0 00	2 87	0.00	0.00	0.00	0.00	0 00	0.25	0 00	0.25	0.00	0.00	0.00	0 24	0 00	0 00	0.00	0 00	0.00	0 23	0.00	0.00	0 00
UNK5	0.97	1.20	5 18	1.49	0.00	0.69	3.48	0 25	0 00	5.00	1 75	2 53	3 58	0 00	8 85	0 87	1.74	1 25	3.00	3.43	0 25	1.25	1 25
UNK69	0 00	0.00	0 00	0.00	0.00	0.23	0.00	0 00	0 00	3.50	1.75	2.53	0.00	0.00	0.00	0.00	0.00	0.50	0 00	0 00	0 00	0 00	0 25
UNK7	0.00	0.00	2.35	0.00	1 27	0 00	0 00	0 75	0.00	0.25	0.75	2.28	2.15	0.00	0.00	0.00	1.24	0.00	0.25	0 00	0 00	0 00	1 25
UNK80	0.00	0.00	0 00	0 00	0 00	0.46	0.00	0.00	0 00	0.00	0 00	0 00	0 00	0.00	0 00	4.35	0.00	0.00	0.00	0 00	0.00	0.00	0.00
UNK88	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0 25	0.00	0.50	0 00	0.00	0.00	0.00	0.00	0 00	0 00	1 00	0.00	0.00	0.00	0.00
VIK7	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00
VIK8a	0 00	0 00	3.76	0 00	0.00	0.00	0.00	0 00	0 00	0.50	0.00	0.00	0.00	12.20	0.00	0 00	0 00	0 00	0 50	0.00	0.00	0.00	0.00
VIKpro	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 25	0 50	1.01	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0 00

Code	LS1	ML1	ML2	ML3	OL1	PC2	SC1	SL1	SL2	SW	T1	W1	W2	Maximum	Mean
ACH14	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0.00	5.61	0.25
ACH15	0.74	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0 00	0.00	1.23	0 00	2.48	0.24
ACH17	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.77	0 05
ACH2	0 00	0 00	0 00	0.00	0.00	0 25	0.00	0.00	0.00	0.00	0.00	0 00	0 00	2.99	0 12
ACH22	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	1.27	0 06
ACH3	2.21	5.50	0.25	0.00	13.02	1.76	0 00	1 00	0 00	0 00	7.65	6 14	15 88	15.88	3.03
ACH6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	1.75	0.06
ACH6a	0.49	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0.49	1.23	0 00	5 32	0.48
ACHbre3	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0.25	0 74	0 00	1.25	0.15
ACHpse	0.25	0 25	0 00	0 00	0 47	0.00	0.00	0.00	0.00	0 00	0.00	0.49	0.00	4.30	0.34
ACHres	0 00	0 00	0.50	0.24	0.00	0.00	0.25	0 00	1.61	3 38	0.25	0.00	0 00	4.50	0 60
AMP1	7.37	8.75	4.27	2.83	39.53	6.28	0.49	3.48	0.00	0.24	4.94	1.23	9 93	39.53	5.46
AMP11	2.46	0 00	0.25	0.94	0.00	0.00	0.25	0.00	0 00	0.00	0 00	1.23	0.00	9 90	1.11
AMP14a	0.00	0.00	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	7.88	0 32
AMP15	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0.00	3 86	0 00	0.00	0.00	3 86	0 15
AMP18	0 00	0 00	0 00	0 00	0 00	0 00	1 97	0 25	0 00	3 62	0 00	0 49	0.25	3.69	0 46
AMP3	0.25	0.00	0.00	0.00	0.00	0.25	0 49	0.00	0.00	1 93	0 25	0.25	1.99	3.48	0.42
AMP6b	0.00	0 00	0.00	0 00	0.00	10 05	0 00	0 00	0 00	0 00	0 00	0 00	0.00	10.05	0.28
AMP9	0 00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	9.57	0 94
AMPcof	6 39	1.00	1.26	0.00	0.00	0.75	1.47	4.23	0.92	9 90	1 98	1 97	6.20	12.17	3 16
AMPcof2	4 18	0.00	0.00	0.00	0 00	0 00	2 46	0 00	0 00	10.87	0 00	0.25	0.50	10.87	1 30
AMPlae	0 00	0.00	0.00	0.00	0.00	0.50	0.00	0 25	0.00	0.00	0 00	0 00	0 00	4.05	0 52
AMPlae2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0 00	0.00	4.88	0 25
AMPlae5	0 00	0.00	0 00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	1.97	0.05
ARDfor	0 00	0.00	0 25	0.00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0 25	0 00	1.74	0 14
BER1	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	0 00	0.24	0.01
BRF1	0.00	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	1.93	0 12
CEN1	0 00	1 25	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0.48	2.47	0.25	0 25	4 24	0.59
CEN10	0.00	0 00	0.00	40.33	0.47	0.00	0.00	0.25	0.00	0 00	2.22	0 00	0.00	40.33	1 22
CEN15	0 00	0.25	0.25	0.00	0.00	0.00	4.67	1.24	0.00	0.24	0 00	0 00	0 00	4.67	0 52
CEN5	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	11 50	0.59
CEN9	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0 24	0 00	0 00	0.00	2.74	0 14
CEN9a	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	2.42	0 08
COC14	0 00	0 00	0.00	0 00	0 00	3.52	0.00	0.00	0.00	0.00	0 00	0 00	0.00	3.52	0 10
COC4	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0.00	0 00	0 00	2 46	0.00	2.46	0 07

Code	LS1	ML1	ML2	ML3	OL1	PC2	SC1	SL1	SL2	SW	T1	W1	W2	Maximum	Mean
COC4a	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	1.45	0.00	0 00	0.00	1 45	0.04
COC9	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 25	1 72	0.16
COCcos	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	1.25	0.05
COCdis	0.74	0.75	0.00	0.24	4.65	1.26	0.00	0.00	0.00	0.24	3.21	0 98	1.99	8 27	1.39
COCpla	0.00	5.00	33.17	0.94	3 49	0.75	3.19	51 00	0 23	2.17	7.41	20.88	6.45	51.00	6 20
COCplae	0.00	0 00	0.25	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	1 72	0 00	3 72	0.38
COCscu	0 25	1 00	18.59	0.47	3 49	0.50	30.47	3.48	2.76	1.21	7.90	5 41	1 74	30 47	3.58
COCscup	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0 00	0.00	1.47	0.00	2.25	0.19
CYCstr	0 00	0 00	0.00	0 00	4.65	0.25	5.65	0.00	0 23	0 24	0.00	0 00	0.25	6.09	0.68
CYCstr2	0.25	2 25	0.75	29.01	0 93	0.00	1.23	0.25	0.00	0.00	20.00	1.72	0.00	29.01	2 25
CYMasp3	4.18	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0.74	1.47	0.50	4.18	0.19
DIP5	0.00	0 00	0.00	0.47	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	5 17	0.36
DIP8	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0 00	8 62	0.32
DIPnot	0.25	0 00	0.00	0 00	0 00	0 00	4 67	0.25	0.00	0 24	0.25	0.98	0 25	4.67	0.29
EPI1	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	10.87	0 00	0.00	0.00	10.87	0.32
EPI1a	0 00	0 25	0 00	0 00	0 00	0 00	0 00	0.00	0.00	7 00	0.00	0.00	0 00	7 00	0.21
FAL11	0.00	0 00	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.48	0.14
FAL2	0.25	0 00	0.00	0.00	0 00	0.00	0.98	0.00	0.00	0.00	0.00	0 00	0 00	14.88	0.57
FAL4	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	2 00	0.06
FAL5	0.74	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 49	1.72	3.97	7.54	0.80
FRA1	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	2 75	0.17
FRA3	0.00	0.00	0.00	0 00	0 23	0.00	0.00	0.00	0 00	0.00	0 00	0 00	0 00	1 93	0 06
FRA7	0.00	0.00	0.00	0.00	0.00	1.51	0.00	0.00	0 00	0 00	0 00	0.00	0 00	1.51	0.04
FRAgeo	1.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 25	0.00	1.72	0.15
FRAvir	0.00	0.00	0.00	0.00	0 23	0.00	0.00	0.00	0.00	0 00	1.98	0.00	0 00	1.98	0 07
GRA2	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	1.25	0.06
GRA3	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	1 41	0 08
GRAmac	0.74	0.00	0.00	0.71	0.23	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	2.82	0.20
GRAmar	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	3 75	0.20
GRAoce	0.00	1 25	0.25	2.83	0.00	0 00	0 00	3 48	1 84	0.00	0 00	0.00	0.00	41.87	2.17
GRAsub	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.98	0 22
GYRatt1	1 23	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	1.23	0.03
GYRbal	0.49	0 00	0.00	0.00	1.16	0.75	0.25	0.00	0.00	0.48	2.47	0.00	0.00	2.49	0 41
MAS2	0 00	0.00	0.00	0.00	0.00	0.00	0.25	0 00	0.00	0.00	0 00	0.00	0.50	1.91	0.11
MAS2a	0 00	0.00	0.25	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0.00	24.88	0 86
MAS3	0 00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	2.15	0.08

Code	LS1	ML1	ML2	ML3	OL1	PC2	SC1	SL1	SL2	SW	T1	W1	W2	Maximum	Mean
NAV1	3.44	0.50	1 51	0.00	0 00	0.25	0.00	0 50	0.69	0.48	1.73	5.65	6 45	8 75	1.96
NAV10	0.25	0.50	1.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	8 87	0.64
NAV2	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	2 00	0.09
NAV3	5.65	0 00	0.00	1.18	2 56	0.25	0.00	0.00	0 00	3.62	0 00	2.95	3 97	11.47	1.98
NAV30	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00
NAV32a	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	1.24	0 06
NAV4	2.70	0 25	0 00	0.47	0 00	0 00	0 00	0.00	0 00	2.66	0.00	0.25	0.25	6 84	0.95
NAV42	0 00	4.25	5.28	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0 25	0.00	0.00	5.28	0.27
NAV43	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	1 21	0 04
NAV44	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	4.91	0 00	4.91	0.14
NAV7b	0.00	0.00	0 00	0 00	6 51	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	6 51	0 18
NAVper	0 25	0.50	0 00	0.47	0.23	0 25	0 00	0 00	0 00	0.00	0.74	1 47	0 99	14 29	1 88
NAVryn	0.00	0 00	0.00	0.00	0.00	0.00	0.25	0.00	0 00	0 00	0 00	0 00	0 00	1.43	0.12
NAVvir	0.00	0.00	0.00	1.42	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	1.42	0.05
NAVvir3	2.70	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.70	0 08
NIT10	0.00	0 00	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	2 25	0.09
NIT6	1.47	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	1 23	0.00	0.25	2.75	0 38
NIT6a	0.00	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	3 75	0.17
NITpan1	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	1.50	0.06
NITscal	0.25	0.00	0 25	0 00	0.00	0 00	0 25	0 25	0 00	0.00	1 23	0 00	0.00	3.50	0 38
NITval	0.49	0.00	1.51	0.00	0.00	1.26	0.25	0.00	0.00	0.48	0 00	0 49	0.00	14.85	1.24
OPE3	2 21	0 50	0 25	0 24	6.98	2.01	0 49	0 25	0.23	0 00	0.25	1.23	0.25	17.12	1 68
OPE6	1.47	0.00	0.00	0.00	0.00	0.25	0.00	0.50	0.00	0.00	0 49	0 98	0.74	6 48	1.18
OPEbur	13 51	10.00	8 04	2 12	0 23	1 26	0 25	1.49	1.84	2.90	1 23	1 47	6.70	64.22	6 88
OPEbur2	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0.00	20.29	0.56
OPEgue	6 14	1 00	15.33	0.24	0.00	4 52	0.00	1 00	1 15	13.29	5.43	1.47	0.00	15.33	3 73
PARsul	0.49	0 00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	0.00	4.94	0.00	0.00	4 94	0 91
PLAdel	1.97	28 75	0.75	10.85	0 00	0 50	0 25	1 49	0 69	1 21	1 98	4.91	3.72	28.75	3.54
PLAdel3	1.23	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	3.50	0.26
PLAdel4	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	1.25	0 06
PLAhau	4 42	10.50	1.26	0.71	6.28	34.92	0.00	0.00	0.00	0.24	1.73	1 23	6.95	34.92	7.27
PLAhau3	0 74	0 00	0.00	0 00	0.00	0 00	0 00	0 00	35.71	0 00	0.00	0.00	0.00	35.71	1 99
PLApol3	1 23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 25	0 00	1.23	0 04
PSEper	0 00	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	1.44	0 08
RHA2	0 00	0 00	0.00	0 00	0 00	0.00	3 69	0.00	0.00	0.00	0 00	0 00	0.00	3 69	0 15

Code	LS1	ML1	ML2	ML3	OL1	PC2	SC1	SL1	SL2	SW	T1	W1	W2	Maximum	Mean
RHA3	0.00	0 00	0.25	0.00	0.00	0.00	34 15	1.99	0 46	1.21	0 00	0 25	0 25	34.15	1 56
rVIK5	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0 25	0.03
STA2	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	2.71	0 09
SYN1	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	3.00	0 10
SYNcam	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0.25	1.50	0 17
SYNfas	0.00	0.00	1.01	0.00	0.00	0.25	0.25	1.24	0.00	1.45	1.98	0 00	0 25	4.75	0.46
UNK100c	0.00	0 00	0.00	0 00	0 00	0.00	0 00	2 49	0.00	0 00	0 00	0.00	0.00	2.49	0 12
UNK102	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	2 24	0.18
UNK102a	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	1 21	0.03
UNK107	6.14	9 25	0 25	0 00	0 00	1 01	0 00	0 00	0.00	0 00	0.00	0.00	0.00	9.25	1.03
UNK117	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00
UNK126	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	9 07	0.25
UNK19	1 23	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	3 95	1.23	0 00	4 00	0.39
UNK19c	0.00	1 00	0 50	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0 00	1 64	0.09
UNK200	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	1 74	0.05
UNK24	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	1.25	0.15
UNK28	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0 00	1.18	0.03
UNK30	0.00	2.25	0 00	0 00	0.00	0 00	0.00	0.75	0 23	0.00	0.00	0 49	0.50	3.25	0 73
UNK37b	0 00	0 00	0.00	2.12	0.00	1.76	0.49	17.91	51.38	0 00	0.00	0 00	0.00	51.38	2.41
UNK43	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0.24	0 00	0.00	0.00	2.87	0 11
UNK5	0.98	1 75	1.01	0 00	2.56	21.36	0 00	0 00	0.00	0 48	4.20	14.00	16.38	21.36	3.08
UNK69	0.49	0 50	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	3 50	0.27
UNK7	1 97	0 00	0 00	0 00	0.00	0 00	0 00	0 25	0.00	0 00	0.00	0.00	0 00	2.35	0.41
UNK80	0.98	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	5.31	0.49	0.00	0 00	5 31	0.32
UNK88	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	2 90	0 00	0 00	0 00	2.90	0.13
VIK7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	2.72	0.00	0.00	2.72	0 08
VIK8a	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	0.00	12.20	0 47
VIKpro	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0.49	0.00	1.01	0 06

Code	AI1	AI2	AI3	CI1	CI2	CI3	GL1	GL2	GL3	GL4	GL5	GL6	GL8	GL10	GL11	GL12	LT1	LT2	LT3	LT4	MC1	MC2	MC3	MC4
ACH11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.73	1.83	0.00	0.00	0.00	0.00
ACH14	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.94	0.00	0.00	0.00	0.00	0.00
ACH15	0.74	5.33	4.75	0.25	0.25	0.24	0.00	0.50	0.24	2.33	0.00	0.00	0.00	3.16	0.00	0.00	3.99	1.22	0.48	0.00	0.00	0.00	0.00	0.00
ACH2	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.73	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00
ACH3	0.74	0.21	1.25	4.75	0.50	0.95	7.86	2.01	1.43	3.36	4.19	3.70	2.67	0.00	0.00	4.16	0.75	1.22	0.00	0.00	0.00	0.00	0.00	0.66
ACH4c	0.00	0.00	0.00	0.00	0.00	3.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ACH6	0.00	0.21	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	3.45	0.00	0.00	0.24	0.00	0.69	0.00	0.00	0.00	0.41	0.00	0.00	0.00	0.00
ACH6a	0.00	0.85	0.75	0.50	0.00	0.00	0.25	0.00	0.00	2.58	3.45	0.46	1.94	0.00	0.25	6.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ACHbre3	0.25	0.21	0.25	1.00	1.25	0.47	0.00	0.50	0.48	0.00	0.00	1.15	0.49	0.24	0.99	0.00	1.25	2.92	0.73	0.00	0.00	0.00	0.00	0.00
ACHpse	0.25	4.69	0.00	1.75	0.75	0.47	1.97	0.25	0.00	1.55	2.22	0.00	0.00	0.00	0.50	0.00	0.25	0.00	0.00	0.20	0.00	0.00	0.00	0.33
ACHres	0.00	0.21	0.25	1.25	0.75	1.42	1.47	0.00	0.00	1.03	7.39	0.00	0.24	0.24	0.25	0.92	0.75	0.49	0.48	0.00	0.00	0.47	0.00	0.00
ACHres3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	1.21	1.02	0.00	0.00	0.00	0.00
AMP1	17.24	10.23	2.50	10.75	10.75	8.53	9.09	6.77	4.76	29.20	6.40	7.39	39.56	1.22	2.97	21.02	2.99	2.43	2.18	0.20	0.75	0.47	0.25	1.32
AMP11	1.23	0.21	0.25	0.50	3.75	0.24	0.00	1.00	1.90	0.00	0.00	0.23	0.00	0.49	0.74	0.00	0.25	0.00	0.97	0.20	0.00	0.00	0.00	0.00
AMP14a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	1.94	0.00	0.00	0.00	0.00	0.00
AMP15	0.00	0.21	0.00	0.00	0.00	0.00	0.49	0.50	0.48	0.26	0.00	1.39	0.00	0.49	0.00	0.00	0.00	0.00	1.45	0.20	2.01	0.95	0.25	0.00
AMP3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	1.90	0.00	0.00
AMP7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.15	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AMP9	0.00	0.21	1.00	0.50	0.50	1.66	0.49	1.00	1.67	0.00	2.96	0.46	6.07	0.00	1.49	1.15	1.00	0.49	3.63	1.42	0.00	0.00	0.76	0.00
AMPcof	1.48	0.21	0.50	0.25	1.75	2.37	1.72	1.00	0.71	0.78	1.48	1.85	0.49	0.73	2.23	0.23	1.75	4.14	3.63	0.20	3.51	3.79	1.51	0.00
AMPcof2	0.74	1.28	1.25	0.75	0.75	1.18	0.00	0.00	0.00	0.26	0.00	0.23	0.00	0.49	0.74	0.23	0.25	0.49	0.24	0.00	0.00	0.24	0.25	0.00
AMPcof3	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.25	0.00	0.00	0.00	1.39	0.00	0.00	0.00	0.46	1.00	0.73	0.24	0.00	0.25	0.71	0.00	0.00
AMPlae	0.49	5.54	0.00	0.00	0.25	0.71	0.98	0.50	2.14	0.78	0.49	0.00	0.00	0.00	0.74	0.46	0.00	0.00	0.24	0.20	0.00	1.90	0.50	0.00
AMPlae1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00
AMPlae1a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AMPlae2	2.46	0.00	0.00	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ARDfor	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.65	0.48	0.41	2.01	0.00	0.76	0.00
BER1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00

Code	AI1	AI2	AI3	CI1	CI2	CI3	GL1	GL2	GL3	GL4	GL5	GL6	GL8	GL10	GL11	GL12	LT1	LT2	LT3	LT4	MC1	MC2	MC3	MC4
BRF1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CEN1	0.25	0.00	54.25	1.75	3.50	0.95	0.00	0.25	0.24	0.00	0.25	0.00	0.00	0.24	0.50	0.00	0.50	0.24	0.73	3.05	0.00	3.32	2.27	0.33
CEN15	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.00
CEN2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	1.01	0.00
CEN5	0.00	0.00	1.25	7.75	14.50	1.18	0.00	0.00	0.00	0.26	0.25	1.85	0.24	0.24	0.74	0.00	0.50	0.97	0.00	0.00	0.00	0.00	0.00	0.99
CEN7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.00	0.00	1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
CEN9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COCcos	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00
COCdis	0.25	0.21	0.00	2.50	1.50	1.42	0.00	2.26	0.95	0.00	0.00	0.00	0.00	0.00	1.24	0.00	0.25	0.49	0.00	0.00	3.26	4.74	1.26	0.66
COChet	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.50	1.19	0.00	0.25	0.00	0.24	0.00	0.74	0.00	0.00	1.22	0.00	1.22	1.75	0.24	0.00	0.00
COCmol	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00
COCpel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.76	0.00
COCpla	1.23	0.43	0.00	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.24	0.24	2.97	0.00	1.50	3.65	1.94	1.22	0.50	0.00	0.25	0.33
COCpla1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COCplae	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.24	0.24	0.00	2.26	0.47	0.00	0.00
COCpse	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.00	0.74	0.00	0.00	4.87	0.48	0.00	6.77	0.71	0.25	0.00
COCscu	0.49	0.00	0.00	2.50	1.25	0.00	0.74	0.50	0.00	0.00	0.00	0.46	0.97	0.24	6.19	0.69	0.00	2.92	0.24	0.41	5.76	3.55	3.02	3.97
COCscup	0.25	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.26	0.00	0.23	0.00	0.00	0.25	0.00	0.00	0.49	0.00	0.00	2.76	1.42	0.50	0.99
CYCstr	1.97	0.00	0.50	0.00	0.50	0.00	0.49	5.26	1.90	0.00	0.00	0.23	0.00	2.43	1.24	0.00	0.00	0.00	2.91	5.08	1.50	12.80	0.00	0.33
CYCstr2	0.00	0.00	0.25	0.00	0.50	0.00	0.25	1.25	0.00	0.26	0.00	0.23	0.00	7.30	1.24	0.00	0.75	0.49	3.63	6.30	0.00	0.00	0.00	0.00
CYMasp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.76	0.00	0.26	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.48	0.20	0.00	0.00	0.00	0.00
DIP9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DIPnot	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.49	0.25	0.46	0.00	0.00	0.24	0.20	0.75	0.00	0.00	0.00
DIPnot2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DIPvac	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.25	0.23	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00
EPIzeb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EUN1	0.74	0.85	0.00	0.00	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FAL2	0.00	0.00	0.00	0.00	0.00	0.47	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Code	AI1	AI2	AI3	CI1	CI2	CI3	GL1	GL2	GL3	GL4	GL5	GL6	GL8	GL10	GL11	GL12	LT1	LT2	LT3	LT4	MC1	MC2	MC3	MC4
FAL5	0.00	0.21	0.25	0.25	0.75	0.71	1.72	1.50	0.00	2.58	3.45	0.23	1.94	0.49	0.00	2.77	0.75	0.24	0.48	0.20	0.75	0.47	1.26	0.99
FAL8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.70	0.00	0.00	0.00	0.00	0.00	0.00
FALsub	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.24	0.00	1.73	0.23	0.00	0.97	0.00	0.00	0.00	1.42	0.00	0.00
FRA1	0.25	0.00	0.00	0.00	0.00	0.00	0.25	0.75	0.48	0.78	0.00	0.00	0.00	0.49	0.50	0.23	4.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FRA3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	3.78	0.00
FRA8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FRAgeo	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.24	0.49	0.25	0.00	0.75	0.00	0.00	0.00	0.25	0.95	0.00	0.00
FRAshu	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.70	0.25	0.00	0.00	1.22	0.00	0.00	0.00	0.00	0.00	0.00
FRAvir	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.00	1.00	0.71	0.00	0.33
GRA2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.27	4.64
GRA3	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GRAarc	0.25	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00
GRAmac	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.49	0.00	0.25	0.00	0.50	0.24	0.48	0.81	0.00	0.00	3.78	0.33
GRAmar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	0.00	0.00	0.00	0.00	0.00	0.97	0.00	5.01	0.00	1.01	1.99
GRAoce	0.00	0.00	0.50	2.50	1.25	0.00	0.00	2.26	0.95	1.55	0.49	0.69	0.97	0.00	0.99	0.00	0.00	2.19	0.00	1.02	5.01	3.32	13.85	5.30
GRAsub	0.00	0.00	0.25	0.25	0.00	0.00	0.49	5.01	3.33	0.00	0.00	0.69	0.00	0.00	0.00	0.00	1.00	0.73	8.47	0.00	0.00	0.00	2.52	3.64
GYRbal	12.56	0.21	0.00	0.25	0.50	0.24	0.74	4.01	1.67	0.26	0.00	0.00	0.00	0.49	0.25	0.00	4.49	5.60	0.24	0.00	0.00	0.71	0.00	0.00
LIC1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.25	0.33
LIC1a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.00	1.39	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.20	0.00	0.00	0.25	0.00
MAS2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.89	0.00	0.20	4.51	0.00	0.00	0.00
MAS2a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	0.00	1.02	0.00	0.00	0.25	0.00
MAS3	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.41	0.00	0.00	0.00	0.00	1.76	0.00
MAS4b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAS5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	1.01	0.00
MAS6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MEL1	0.00	0.00	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.00	0.00	0.00	0.00	0.00	1.94	0.61	0.00	0.47	2.52	1.32
NAV1	1.23	14.07	0.50	1.25	2.00	0.95	2.21	1.50	1.19	0.00	1.97	2.31	0.00	2.19	0.00	0.00	0.25	1.22	2.42	0.00	1.50	4.03	3.27	0.33
NAV10	0.74	0.85	0.00	0.00	1.75	1.18	0.25	0.25	0.24	0.78	1.97	0.00	0.49	0.24	0.74	0.00	0.50	0.24	3.39	0.41	0.00	0.00	1.26	2.32

Code	AI1	AI2	AI3	CI1	CI2	CI3	GL1	GL2	GL3	GL4	GL5	GL6	GL8	GL10	GL11	GL12	LT1	LT2	LT3	LT4	MC1	MC2	MC3	MC4
NAV12	0.00	0.00	0.00	0.00	0.75	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.22	4.84	0.00	0.00	0.00	1.26	1.32
NAV14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
NAV16	0.00	0.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	0.00	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.50	0.00
NAV19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.00	0.00	0.00
NAV3	0.49	3.20	0.00	0.00	0.00	1.42	0.98	0.00	0.48	0.00	1.48	0.00	0.00	0.24	0.00	0.00	2.74	0.24	5.57	0.00	0.75	0.47	0.00	0.00
NAV30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00
NAV34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NAV36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NAV4	0.00	0.00	0.00	0.00	0.25	0.71	0.00	1.75	4.76	0.00	0.00	0.92	0.00	0.00	0.50	0.23	0.50	3.41	0.00	0.00	0.25	0.71	0.00	0.33
NAVper	0.25	1.28	0.00	0.00	2.75	0.47	0.74	1.50	0.00	0.78	3.94	3.23	0.00	0.97	3.71	0.23	2.74	3.89	0.97	0.00	3.76	5.45	1.26	0.00
NAVryn	7.64	0.00	0.00	0.00	0.25	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NIT11a	2.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NIT2	0.49	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.97	0.00	0.00	0.00	0.24	0.00	0.41	0.25	0.24	0.00	0.00
NIT6	3.94	1.07	0.00	0.00	0.50	1.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.14	0.00	0.00	1.25	1.22	1.45	0.41	0.25	0.00	0.00	0.00
NIT6a	1.72	1.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.50	0.00	1.00	1.95	0.48	0.00	0.00	0.00	0.00	0.00
NITlan	0.00	1.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.25	0.00	0.00	0.00	0.48	0.00	2.26	0.95	0.00	0.99
NITpan	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.90	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.75	1.46	0.48	0.00	8.77	0.00	0.00	0.00
NITpan1	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.75	2.62	0.26	0.00	0.46	1.70	0.24	0.50	0.00	0.00	1.22	0.24	1.02	0.00	0.71	1.01	0.00
NITscal	0.74	0.43	0.00	0.75	0.50	0.00	0.00	0.75	0.24	1.29	0.00	0.00	0.00	4.62	2.72	0.00	1.50	0.24	0.24	0.61	2.26	1.18	3.53	2.32
NITval	0.74	0.43	0.25	0.00	5.50	1.42	0.98	0.25	0.00	4.13	10.84	2.31	0.49	0.24	0.25	8.08	3.49	0.24	1.94	0.41	0.25	0.71	0.25	0.00
OPE3	0.99	2.99	1.75	2.50	3.00	0.71	2.95	4.76	4.29	1.81	0.25	5.31	1.21	4.14	4.21	1.39	3.24	0.24	0.00	0.00	0.00	0.00	0.00	0.00
OPE6	0.00	0.43	0.50	0.50	3.25	5.69	10.07	8.77	10.48	0.00	0.00	0.23	1.46	3.65	3.22	0.92	5.49	1.46	1.69	21.14	1.00	1.66	0.76	3.31
OPEbur	0.49	0.64	0.25	0.25	2.00	4.50	20.88	3.26	6.43	3.36	0.25	5.77	7.04	2.92	6.44	1.15	1.75	0.00	0.24	19.72	0.00	0.00	0.00	0.00
OPEbur2	0.00	0.64	0.00	7.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OPEgue	0.00	0.00	0.00	0.25	1.50	2.13	13.76	6.52	8.57	1.55	0.25	7.39	1.94	1.95	5.69	0.46	8.23	9.25	6.05	4.67	0.50	2.84	0.76	4.30
PARsul	3.94	0.00	12.00	0.00	0.75	0.00	0.74	4.26	3.10	0.26	0.00	0.69	1.46	0.49	0.25	0.00	2.24	0.24	0.24	5.08	0.00	0.00	0.00	0.00
PLAdel	14.04	9.59	1.50	6.25	1.25	8.53	1.72	1.25	0.00	1.81	9.11	3.46	2.43	5.84	1.49	8.08	1.25	0.00	0.73	0.00	1.00	4.98	3.78	13.25
PLAdel3	1.72	2.35	2.75	0.75	0.75	2.61	0.00	0.00	0.00	2.84	0.00	0.46	3.16	12.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.25	0.33

Code	AI1	AI2	AI3	CI1	CI2	CI3	GL1	GL2	GL3	GL4	GL5	GL6	GL8	GL10	GL11	GL12	LT1	LT2	LT3	LT4	MC1	MC2	MC3	MC4
PLAdel4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PLAdis	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	5.43	0.00	0.00	0.00	1.70	0.25	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PLAhau	3.94	12.37	1.25	6.75	6.25	11.37	3.93	5.01	3.57	11.37	21.43	25.40	11.89	6.57	6.19	29.79	3.99	4.87	3.39	0.00	7.77	11.14	3.02	14.57
PLAhau2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.47	0.00	0.00
PLAhau3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PLApol2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.00	0.25	0.00	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PSEper	0.00	0.00	0.00	0.00	0.00	0.00	1.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.24	0.48	0.00	0.00	0.00	0.00	2.32
RHA2	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.49	1.21	1.42	4.01	0.00	1.51	0.66
RHA3	0.00	0.00	0.00	0.25	0.25	0.00	0.00	1.25	0.00	0.26	0.49	2.31	0.49	2.92	1.73	0.46	1.25	0.49	2.42	7.72	3.76	0.71	10.08	3.31
rVIK5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
STA4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SYN1	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.24	0.00	0.25	1.15	0.00	0.97	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SYN3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.49	0.49	0.48	0.41	0.00	0.00	0.00	0.00
SYNcam	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50	0.00	0.25	0.66
SYNfas	0.74	0.64	0.00	0.00	0.25	0.00	0.00	1.25	2.86	1.29	0.00	1.15	0.00	1.70	8.17	0.00	1.50	0.00	0.97	0.20	1.00	1.42	1.51	4.64
UNK1	0.74	0.00	0.25	0.00	1.00	0.00	0.00	0.00	0.24	0.00	1.23	0.00	0.00	1.22	0.00	0.00	0.00	0.00	0.00	0.00	0.50	1.90	0.25	0.00
UNK100c	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK107	1.72	6.82	4.75	16.50	0.25	1.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK111	0.00	0.00	0.00	0.00	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK116a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK117	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK19	0.49	0.00	0.00	0.00	0.25	0.95	0.74	0.50	0.00	0.52	0.74	0.00	0.49	0.73	0.25	0.69	0.00	0.49	0.00	0.00	0.50	2.37	0.50	0.99
UNK23	0.00	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	0.00	0.25	0.23	0.00	0.00	0.00	0.00	0.25	0.24	2.42	0.20	0.00	0.95	1.51	0.99
UNK24	0.00	0.21	0.00	1.25	0.75	0.00	0.25	0.25	0.71	0.26	0.00	0.00	0.73	0.00	0.00	0.69	0.25	0.00	0.00	0.00	0.00	0.24	0.00	0.00
UNK28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.00	1.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00
UNK30	0.49	3.84	0.25	1.00	1.00	0.00	0.25	1.25	8.10	4.39	0.00	3.23	2.43	0.00	0.50	0.69	1.00	0.73	0.24	0.00	0.00	0.00	3.02	3.97
UNK31a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Code	AI1	AI2	AI3	CI1	CI2	CI3	GL1	GL2	GL3	GL4	GL5	GL6	GL8	GL10	GL11	GL12	LT1	LT2	LT3	LT4	MC1	MC2	MC3	MC4
UNK4	0.00	0.00	0.00	0.00	1.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.50	0.00	0.48	0.00	0.00	0.00	0.00	0.00
UNK43	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	1.19	0.00	0.00	0.00	0.00	2.43	2.48	0.00	0.00	0.00	0.00	1.22	0.50	0.00	0.00	0.00
UNK5	0.25	0.64	1.00	5.25	6.50	21.33	2.46	1.25	0.24	2.33	5.17	2.08	0.00	0.00	0.00	1.15	0.75	0.49	0.97	0.20	1.50	1.18	0.76	1.66
UNK57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK62	0.00	0.21	0.00	0.25	0.25	0.24	0.00	0.00	0.00	0.26	0.25	0.00	0.24	0.00	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK69	0.25	0.43	0.75	0.00	0.75	0.00	0.25	0.75	5.00	2.07	0.00	1.15	3.16	0.00	0.25	0.00	0.25	0.24	0.00	0.20	0.00	1.18	0.76	0.66
UNK69a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK7	0.00	0.43	0.00	1.75	0.50	0.00	0.25	0.25	0.00	0.78	0.74	1.15	0.24	3.65	2.72	0.46	0.25	0.97	4.60	2.03	1.25	4.27	4.28	1.66
UNK80	0.00	0.00	0.00	0.00	0.00	0.00	0.74	1.25	0.24	0.26	0.00	1.15	0.00	1.46	0.74	0.23	4.24	0.00	0.24	0.81	0.00	0.00	0.50	0.00
UNK87a	0.00	0.00	0.00	0.00	0.75	0.00	2.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK89	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.26	0.00	0.46	0.00	0.00	1.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VIK10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VIK3	0.00	0.00	0.00	1.25	0.00	0.71	0.00	0.25	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VIK8a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Code	MC5	P3	P4	P5	P6	P7	P9	P10	P12	P13	P14	P15	P16	P17	SI2	SYD1	TAM1	WPB1	WPB2	WPB3	WPB4
ACH11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ACH14	0.00	0.00	0.00	4.71	1.73	5.99	0.00	0.24	1.22	21.16	0.00	9.09	3.38	2.47	0.00	0.00	0.00	1.21	0.00	0.00	0.00
ACH15	0.00	0.00	0.00	0.00	0.00	1.25	0.00	0.00	0.00	0.23	0.00	1.67	0.00	0.00	0.26	0.00	0.00	0.00	0.00	0.72	4.68
ACH2	0.00	0.25	0.25	0.47	0.25	0.00	0.25	0.24	1.22	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.25
ACH3	0.00	1.24	0.00	2.12	0.25	1.00	0.00	0.00	0.49	4.19	0.00	0.72	1.21	1.23	0.00	2.84	0.00	1.21	0.85	0.00	3.45
ACH4c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ACH6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.77	0.76	0.00	0.28	0.00	0.00
ACH6a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.31	0.00	0.00	1.93	2.22
ACHbre3	0.00	0.75	1.23	1.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.77	0.00	0.00	0.00	0.00	0.00	1.48
ACHpse	0.00	0.00	0.49	0.24	0.74	0.25	0.50	0.00	0.00	0.00	0.25	0.48	3.62	1.98	0.26	0.26	0.00	2.43	4.56	0.00	0.00
ACHres	0.52	0.00	0.00	0.00	0.00	0.75	0.00	0.00	0.00	1.16	0.00	0.96	0.24	0.25	0.26	0.00	0.25	0.97	0.00	0.00	0.74
ACHres3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AMP1	0.52	0.50	0.00	4.47	9.90	8.23	5.22	0.00	3.42	11.16	0.98	0.48	2.90	4.69	0.26	11.08	3.05	14.08	7.12	7.23	10.59
AMP11	0.26	0.25	0.00	0.47	0.99	0.75	0.00	0.00	1.47	1.63	1.72	1.91	0.00	0.25	3.09	0.00	0.00	0.97	0.00	1.45	0.00
AMP14a	0.00	0.00	0.00	2.59	4.46	0.00	0.00	0.00	0.00	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AMP15	0.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.49	0.00	0.00	0.00	1.03	0.26	0.51	0.00	0.00	0.24	0.00
AMP3	1.81	0.00	0.00	1.18	8.17	15.21	0.00	0.00	0.73	0.00	0.00	1.20	2.42	0.00	0.00	0.00	0.00	0.73	0.00	0.00	0.00
AMP7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AMP9	0.52	0.00	0.00	0.24	0.74	0.25	6.47	0.00	0.00	1.40	0.49	0.48	1.21	2.72	0.00	0.00	0.25	0.97	0.85	4.82	0.25
AMPcof	9.33	1.00	0.00	0.24	0.50	1.75	0.75	0.24	0.49	0.93	0.49	0.24	1.69	1.23	1.80	0.77	2.29	6.80	4.84	1.20	1.23
AMPcof2	0.52	0.25	0.25	0.00	0.00	0.25	0.00	0.00	1.22	2.56	0.00	0.00	1.45	0.25	1.80	0.00	0.00	3.40	1.99	1.45	2.46
AMPcof3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00
AMPlae	0.78	0.00	0.00	0.71	1.24	3.24	2.74	0.00	0.24	1.16	0.00	3.35	0.00	0.25	1.29	0.00	0.25	0.49	0.28	0.00	0.25
AMPlae1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AMPlae1a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AMPlae2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.91	1.45	2.47	1.29	0.00	0.00	6.31	0.57	0.96	1.48
ARDfor	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.57	0.24	0.00
BER1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.87	0.00	0.00	0.00	0.00	0.00	0.00

Code	MC5	P3	P4	P5	P6	P7	P9	P10	P12	P13	P14	P15	P16	P17	SI2	SYD1	TAM1	WPB1	WPB2	WPB3	WPB4
BRF1	0.00	0.00	0.00	0.00	0.99	1.25	0.00	0.00	0.00	0.47	0.00	0.00	1.21	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CEN1	1.81	0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.24	0.47	39.31	0.00	0.24	0.00	1.29	0.77	0.51	0.00	1.14	6.27	1.23
CEN15	0.00	0.00	6.91	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.25
CEN2	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00
CEN5	0.52	0.25	0.25	1.41	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.24	0.48	0.49	1.55	9.79	3.82	0.00	1.42	3.37	3.20
CEN7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CEN9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.46	0.00	0.48	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COCcos	0.00	0.25	0.00	0.24	1.73	0.75	0.75	0.24	2.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COCdis	2.07	18.66	0.00	17.18	6.93	5.24	6.97	56.22	17.85	1.86	0.00	0.48	0.48	0.00	0.77	0.77	0.25	0.73	0.28	1.45	1.72
COChet	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.49	0.00	0.00	0.00	0.49	0.00	0.00	0.00
COCmol	0.00	0.25	0.00	4.71	0.00	0.00	4.23	0.00	1.47	0.00	0.00	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.00	0.00	0.00
COCpel	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.31	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COCpla	5.18	7.46	0.00	0.00	0.00	0.00	0.50	0.00	0.98	0.00	0.00	2.63	3.38	0.25	5.93	0.00	0.51	0.49	0.57	0.48	0.00
COCpla1	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.48	2.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COCplae	1.30	0.00	0.00	0.24	0.00	0.00	3.48	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.52	0.51	0.00	0.00	0.24	0.25
COCpse	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	1.80	0.51	0.00	0.00	0.00	0.74
COCscu	3.11	4.73	0.49	2.82	1.49	1.50	3.73	5.50	3.91	0.23	0.00	0.24	0.00	0.00	1.55	2.32	0.00	0.73	0.85	1.69	1.23
COCscup	0.52	0.25	0.00	0.71	0.00	0.00	8.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.28	0.24	1.23
CYCstr	2.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52	1.29	1.27	0.00	0.00	0.24	0.00
CYCstr2	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.00	2.80	0.00	0.00	0.00	0.00
CYMasp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.32	0.00	0.00	0.00	0.00	0.00
DIP9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DIPnot	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.24	0.00	0.00	0.00	1.02	0.00	0.28	0.00	0.00
DIPnot2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	0.47	0.00	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DIPvac	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.72	0.00	0.26	0.00	0.00	0.73	1.42	0.24	0.00
EPIzeb	0.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	9.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EUN1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.00	0.00	0.00	1.14	0.00	0.25
FAL2	0.00	0.00	0.00	0.00	0.50	2.00	0.75	0.00	0.00	0.00	0.00	3.11	0.48	1.73	0.26	0.00	0.00	0.49	0.00	0.24	0.00

Code	MC5	P3	P4	P5	P6	P7	P9	P10	P12	P13	P14	P15	P16	P17	SI2	SYD1	TAM1	WPB1	WPB2	WPB3	WPB4
FAL5	0.00	0.00	0.00	0.47	1.98	0.00	0.25	0.00	0.00	0.00	0.00	0.24	0.72	1.48	0.00	0.00	2.54	0.24	0.28	1.20	0.25
FAL8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FALsub	0.00	0.00	0.00	0.00	0.00	0.00	3.48	0.00	0.24	0.00	0.00	0.96	0.00	0.00	0.00	0.00	0.00	0.24	0.28	0.24	0.00
FRA1	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.23	0.00	0.24	0.48	0.00	0.00	0.00	0.25	0.00	0.57	0.72	0.74
FRA3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FRA8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.79	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FRAgeo	0.00	0.00	1.98	0.00	0.00	0.00	0.75	0.24	0.49	0.23	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FRAshu	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.02	0.00	0.00	0.00	0.00
FRAvir	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.52	1.27	0.00	0.00	0.00	0.00
GRA2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GRA3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
GRAarc	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	1.23	0.00	0.00	0.25	0.26	0.00	0.00	0.00	0.00	0.00	0.00
GRAmac	1.55	0.25	0.00	0.47	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00
GRAmar	0.00	2.49	0.00	4.24	0.00	0.00	2.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.77	0.00	0.00	0.00	0.00	0.25
GRAoce	0.26	3.73	0.00	3.06	0.00	0.00	0.00	0.72	0.00	0.00	0.00	2.63	0.00	0.00	0.52	1.29	0.51	0.00	0.57	0.48	0.99
GRAsub	6.74	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72	0.00	0.00	0.00	0.52	1.02	0.00	0.00	0.00	0.00
GYRbal	0.00	1.74	0.00	0.24	0.25	0.75	3.48	0.48	0.24	0.00	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.00	0.00	0.48	0.00
LIC1	1.55	0.00	0.00	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LIC1a	1.55	0.00	0.00	0.00	0.50	0.75	0.00	0.00	0.98	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAS2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.99
MAS2a	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.24	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.48
MAS3	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAS4b	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MAS5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
MAS6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.00
MEL1	1.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.46	0.00	0.00	0.00	0.00	0.77	0.51	0.00	0.00	0.00	0.00
NAV1	0.52	1.24	0.00	1.18	2.23	0.75	1.24	3.11	0.00	3.72	3.19	0.24	0.00	0.00	7.73	0.26	0.00	0.00	0.00	0.24	0.49
NAV10	1.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.16	0.00	0.74	0.72	0.24	0.00	0.52	0.52	2.29	0.00	0.00	0.24	0.25

Code	MC5	P3	P4	P5	P6	P7	P9	P10	P12	P13	P14	P15	P16	P17	SI2	SYD1	TAM1	WPB1	WPB2	WPB3	WPB4
NAV12	5.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.27	0.00	0.00	0.24	0.00
NAV14	1.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.00	0.00	0.00
NAV16	6.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.00	1.02	0.00	0.00	0.00	0.00
NAV19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.27	0.00	0.00	0.00	0.00
NAV3	0.26	0.00	0.25	0.00	1.98	0.25	0.00	0.00	0.00	0.00	0.00	2.87	1.21	0.25	8.76	0.26	1.02	0.73	1.14	0.00	1.97
NAV30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.87	0.00	0.00	0.00	0.00	0.00	0.00
NAV34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NAV36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NAV4	0.26	0.00	0.49	0.00	3.47	0.50	0.00	0.00	0.00	0.00	0.00	0.24	0.24	0.49	9.54	0.52	0.00	0.00	0.00	0.00	0.00
NAVper	0.00	0.50	0.00	0.94	0.00	0.50	1.99	0.48	3.67	0.00	0.00	0.48	0.24	2.47	2.84	1.03	12.21	1.46	3.70	1.20	6.65
NAVryn	0.00	0.00	0.00	0.00	3.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.03	0.00	0.00	0.00	0.00	0.24	0.49
NIT11a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NIT2	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	2.21	0.00	0.00	0.00	0.77	0.00	0.51	0.00	0.00	0.00	0.25
NIT6	0.00	0.00	0.49	0.00	0.00	0.25	0.00	0.00	0.49	0.00	0.25	0.00	0.00	0.25	2.32	0.00	0.76	0.00	0.00	0.00	0.00
NIT6a	0.00	0.50	0.25	0.24	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00
NITlan	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25
NITpan	0.52	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.00	0.00	0.00	0.00	0.00
NITpan1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	6.60	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.76	0.00	0.00	0.00	0.00
NITscal	1.55	1.24	0.00	0.00	0.50	0.25	1.24	0.24	0.49	0.23	5.16	0.00	0.00	0.00	0.26	0.00	0.25	0.00	0.57	0.24	0.25
NITval	3.37	0.75	0.25	2.35	1.98	2.49	2.99	1.44	8.07	2.09	0.00	0.72	0.24	0.00	1.55	0.26	0.76	0.24	1.99	0.00	0.49
OPE3	2.33	0.00	0.00	0.00	0.25	4.99	0.50	1.20	1.22	5.81	1.72	0.48	0.97	0.00	0.26	0.77	0.00	0.24	5.70	1.69	5.91
OPE6	2.07	7.71	8.40	6.59	6.19	2.74	5.72	1.44	0.00	0.93	0.00	0.24	0.24	1.23	0.52	1.80	3.82	0.73	5.41	1.45	0.74
OPEbur	0.00	21.64	42.47	3.53	0.00	1.25	0.00	0.00	0.73	0.47	0.25	0.24	0.00	0.49	0.00	0.00	4.83	0.00	9.12	3.13	4.19
OPEbur2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OPEgue	0.78	10.70	27.65	7.53	1.98	2.49	7.96	3.35	0.00	0.23	0.00	0.00	0.00	0.74	0.52	7.99	7.38	0.00	1.71	0.00	0.00
PARsul	0.00	0.00	0.99	0.00	0.00	0.00	0.00	4.78	0.00	0.00	0.00	0.00	0.00	0.00	1.29	12.37	0.00	0.00	1.14	3.37	3.69
PLAdel	1.30	2.24	0.99	0.47	1.24	0.50	0.00	0.00	0.24	2.09	0.00	1.44	4.59	1.23	1.80	4.38	3.05	5.10	4.84	6.51	0.25
PLAdel3	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.24	1.69	0.00	0.26	2.58	0.00	3.40	2.85	2.65	2.22

Code	MC5	P3	P4	P5	P6	P7	P9	P10	P12	P13	P14	P15	P16	P17	SI2	SYD1	TAM1	WPB1	WPB2	WPB3	WPB4
PLAdel4	0.00	0.25	1.48	0.47	0.25	2.24	0.00	0.00	0.00	1.40	0.00	0.24	0.00	0.00	0.00	0.00	0.00	2.91	3.99	5.30	0.00
PLAdis	0.00	0.00	0.00	0.00	0.00	0.00	1.99	0.24	0.00	0.47	0.00	4.07	0.97	0.49	0.00	0.52	0.00	0.00	0.00	0.00	0.00
PLAhau	2.59	2.24	0.25	7.06	6.68	5.99	5.72	5.50	5.38	7.21	0.25	18.42	41.79	57.53	9.79	10.57	12.72	20.63	2.56	2.17	16.01
PLAhau2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.27	0.00	0.00	0.00	0.00
PLAhau3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.25	0.97	2.28	0.00	0.00
PLApol2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	1.45	0.00
PSEper	1.04	0.00	0.49	1.18	2.48	0.50	2.49	0.24	1.47	1.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RHA2	0.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.00
RHA3	3.11	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.49	0.72	0.00	0.00	0.26	1.29	0.25	0.00	0.00	0.00	0.00
rVIK5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.00	0.00	0.00	1.55	0.00	0.00	0.00	0.00	0.24	0.00
STA4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.98	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SYN1	0.52	0.25	0.00	0.71	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26	0.25	0.00	0.00	0.00	0.00
SYN3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SYNcam	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.20	0.00	0.00	0.00	0.00	0.00	0.00	0.77	0.00	0.00	0.00	0.00	0.24	0.25
SYNfas	1.30	0.50	0.00	1.88	0.25	0.75	0.75	0.48	0.24	0.00	0.00	0.24	0.00	0.00	0.26	2.58	1.02	0.00	0.00	0.48	0.25
UNK1	0.00	0.00	0.00	1.41	0.00	0.25	2.74	0.00	0.00	0.00	1.47	0.00	0.00	2.22	0.00	0.00	0.00	1.21	0.00	0.72	0.25
UNK100c	0.00	0.75	0.49	0.00	0.50	1.25	0.00	0.00	0.24	0.70	0.00	0.96	6.28	1.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK107	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.24	3.49	0.00	0.00	0.00	0.00	0.26	0.00	0.00	1.21	0.57	5.54	2.96
UNK111	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK116a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK117	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.03	0.00	0.00	0.00	0.00	0.00	0.00
UNK14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK19	1.55	1.74	0.00	2.35	0.50	0.75	1.24	1.67	6.60	2.33	0.25	0.24	0.00	0.00	0.00	0.26	0.00	2.18	0.28	0.96	0.00
UNK23	0.78	0.00	0.00	0.24	0.00	0.00	0.00	0.00	1.22	0.00	0.00	0.24	0.00	0.00	0.26	0.00	0.25	0.00	0.00	0.00	0.00
UNK24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.00
UNK28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.55	0.26	0.00	0.00	0.00	0.00	0.00
UNK30	0.52	0.25	0.00	0.47	0.50	0.25	0.00	0.00	0.73	2.79	1.47	1.67	1.21	0.49	0.26	4.38	5.09	0.00	2.56	1.93	3.20
UNK31a	0.00	0.00	0.00	2.35	0.50	0.00	0.00	0.00	0.00	2.79	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.73	0.00	0.00	0.00

Code	MC5	P3	P4	P5	P6	P7	P9	P10	P12	P13	P14	P15	P16	P17	SI2	SYD1	TAM1	WPB1	WPB2	WPB3	WPB4
UNK4	0.26	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	1.72	0.00	0.00	0.00	0.00	0.26	0.51	0.00	0.00	0.00	0.00
UNK43	2.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.53	0.00	0.00	0.00	0.00
UNK5	3.37	1.00	0.99	3.06	3.47	4.49	1.00	1.20	2.44	2.33	2.21	3.11	5.07	2.96	5.67	2.32	1.02	9.95	5.70	2.89	1.97
UNK57	0.52	0.00	0.00	0.00	1.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK62	0.26	0.00	0.00	0.00	3.22	3.49	0.00	0.00	0.24	0.70	0.00	0.24	3.86	0.25	0.00	0.00	0.00	0.00	1.42	1.45	0.00
UNK64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.03	0.00	0.00	0.00	0.00	0.00
UNK69	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.47	0.00	0.00	0.00	0.49	0.00	1.03	0.25	0.00	1.14	5.30	1.48
UNK69a	0.00	0.00	0.00	0.00	0.99	9.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK7	5.18	0.00	0.00	0.00	9.90	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52	0.26	0.51	0.97	2.56	0.72	0.49
UNK80	0.00	0.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK87a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK89	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VIK10	0.00	0.00	0.00	0.00	0.25	0.75	0.00	0.00	0.00	2.79	0.00	0.00	0.72	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00
VIK3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	0.85	3.61	0.00
VIK8a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.70	0.49	0.48	0.00	0.00	0.00	0.00	0.00	0.24	3.13	5.30	0.00

Code	Maximum	Mean
ACH11	1.83	0.07
ACH14	21.16	1.19
ACH15	5.33	0.72
ACH2	1.22	0.12
ACH3	7.86	1.36
ACH4c	3.55	0.08
ACH6	3.45	0.16
ACH6a	6.93	0.56
ACHbre3	2.92	0.42
ACHpse	4.69	0.69
ACHres	7.39	0.53
ACHres3	1.21	0.05
AMP1	39.56	6.78
AMP11	3.75	0.60
AMP14a	4.46	0.27
AMP15	2.01	0.27
AMP3	15.21	0.76
AMP7	1.15	0.04
AMP9	6.47	1.07
AMPcof	9.33	1.65
AMPcof2	3.40	0.60
AMPcof3	1.39	0.16
AMPlae	5.54	0.72
AMPlae1	6.36	0.16
AMPlae1a	1.15	0.03
AMPlae2	6.31	0.46
ARDfor	3.65	0.23
BER1	3.87	0.10

Code	Maximum	Mean
BRF1	1.25	0.09
CEN1	54.25	2.81
CEN15	6.91	0.20
CEN2	1.01	0.05
CEN5	14.50	1.29
CEN7	1.49	0.05
CEN9	2.46	0.08
COCcos	2.69	0.15
COCdis	56.22	3.58
COChet	1.75	0.20
COCmol	4.71	0.26
COCpel	4.31	0.14
COCpla	7.46	0.97
COCpla1	2.44	0.07
COCplae	3.48	0.26
COCpse	6.77	0.40
COCscu	6.19	1.56
COCscup	8.96	0.45
CYCstr	12.80	0.95
CYCstr2	7.30	0.58
CYMasp	2.76	0.14
DIP9	1.62	0.04
DIPnot	1.02	0.11
DIPnot2	1.20	0.05
DIPvac	1.42	0.11
EPIzeb	9.83	0.23
EUN1	1.14	0.10
FAL2	3.11	0.24

Code	Maximum	Mean
FAL5	3.45	0.70
FAL8	1.70	0.04
FALsub	3.48	0.23
FRA1	4.24	0.25
FRA3	3.78	0.09
FRA8	2.79	0.09
FRAgeo	1.98	0.19
FRAshu	1.70	0.10
FRAvir	1.27	0.11
GRA2	4.64	0.19
GRA3	16.75	0.38
GRAarc	1.23	0.06
GRAmac	3.78	0.23
GRAmar	5.01	0.44
GRAoce	13.85	1.28
GRAsub	8.47	0.80
GYRbal	12.56	0.89
LIC1	1.55	0.07
LIC1a	1.55	0.14
MAS2	4.51	0.21
MAS2a	1.48	0.09
MAS3	3.41	0.13
MAS4b	2.99	0.07
MAS5	1.01	0.04
MAS6	2.51	0.07
MEL1	16.46	0.61
NAV1	14.07	1.57
NAV10	4.16	0.65

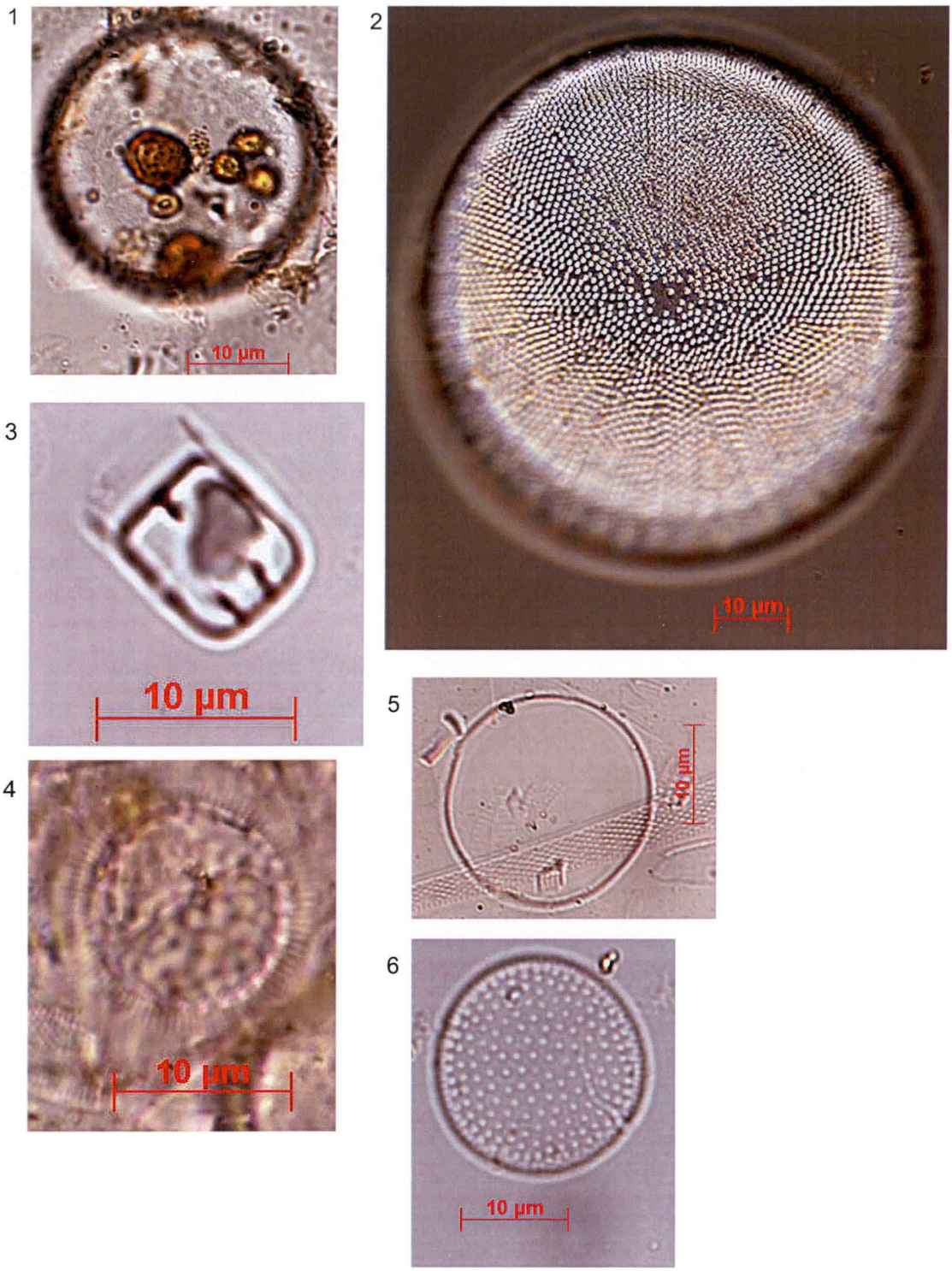
Code	Maximum	Mean
NAV12	5.44	0.37
NAV14	1.81	0.07
NAV16	6.48	0.22
NAV19	1.27	0.03
NAV3	8.76	0.87
NAV30	3.87	0.09
NAV34	2.48	0.06
NAV36	2.63	0.06
NAV4	9.54	0.67
NAVper	12.21	1.74
NAVryn	7.64	0.32
NIT11a	2.71	0.06
NIT2	2.21	0.17
NIT6	4.14	0.45
NIT6a	1.95	0.19
NITlan	2.26	0.15
NITpan	8.77	0.34
NITpan1	6.60	0.43
NITscal	5.16	0.81
NITval	10.84	1.67
OPE3	5.91	1.77
OPE6	21.14	3.19
OPEbur	42.47	3.99
OPEbur2	7.00	0.17
OPEgue	27.65	3.77
PARsul	12.37	1.41
PLAdel	14.04	3.19
PLAdel3	12.90	1.07

Code	Maximum	Mean
PLAdel4	5.30	0.41
PLAdis	5.43	0.37
PLAhau	57.53	10.15
PLAhau2	1.27	0.04
PLAhau3	2.28	0.10
PLApol2	1.45	0.08
PSEper	2.49	0.36
RHA2	4.01	0.26
RHA3	10.08	1.03
rVIK5	1.55	0.05
STA4	1.20	0.05
SYN1	1.15	0.14
SYN3	5.49	0.15
SYNcam	1.50	0.13
SYNfas	8.17	0.89
UNK1	2.74	0.39
UNK100c	6.28	0.29
UNK107	16.50	1.02
UNK111	1.25	0.03
UNK116a	1.47	0.03
UNK117	1.03	0.02
UNK14	1.50	0.03
UNK19	6.60	0.76
UNK23	2.42	0.25
UNK24	1.25	0.14
UNK28	1.55	0.09
UNK30	8.10	1.43
UNK31a	2.79	0.15

Code	Maximum	Mean
UNK4	1.72	0.14
UNK43	2.48	0.26
UNK5	21.33	2.74
UNK57	1.73	0.06
UNK62	3.86	0.38
UNK64	1.03	0.02
UNK69	5.30	0.63
UNK69a	9.98	0.24
UNK7	9.90	1.19
UNK80	4.24	0.28
UNK87a	2.95	0.08
UNK89	1.49	0.06
VIK10	2.79	0.11
VIK3	3.61	0.18
VIK8a	5.30	0.23

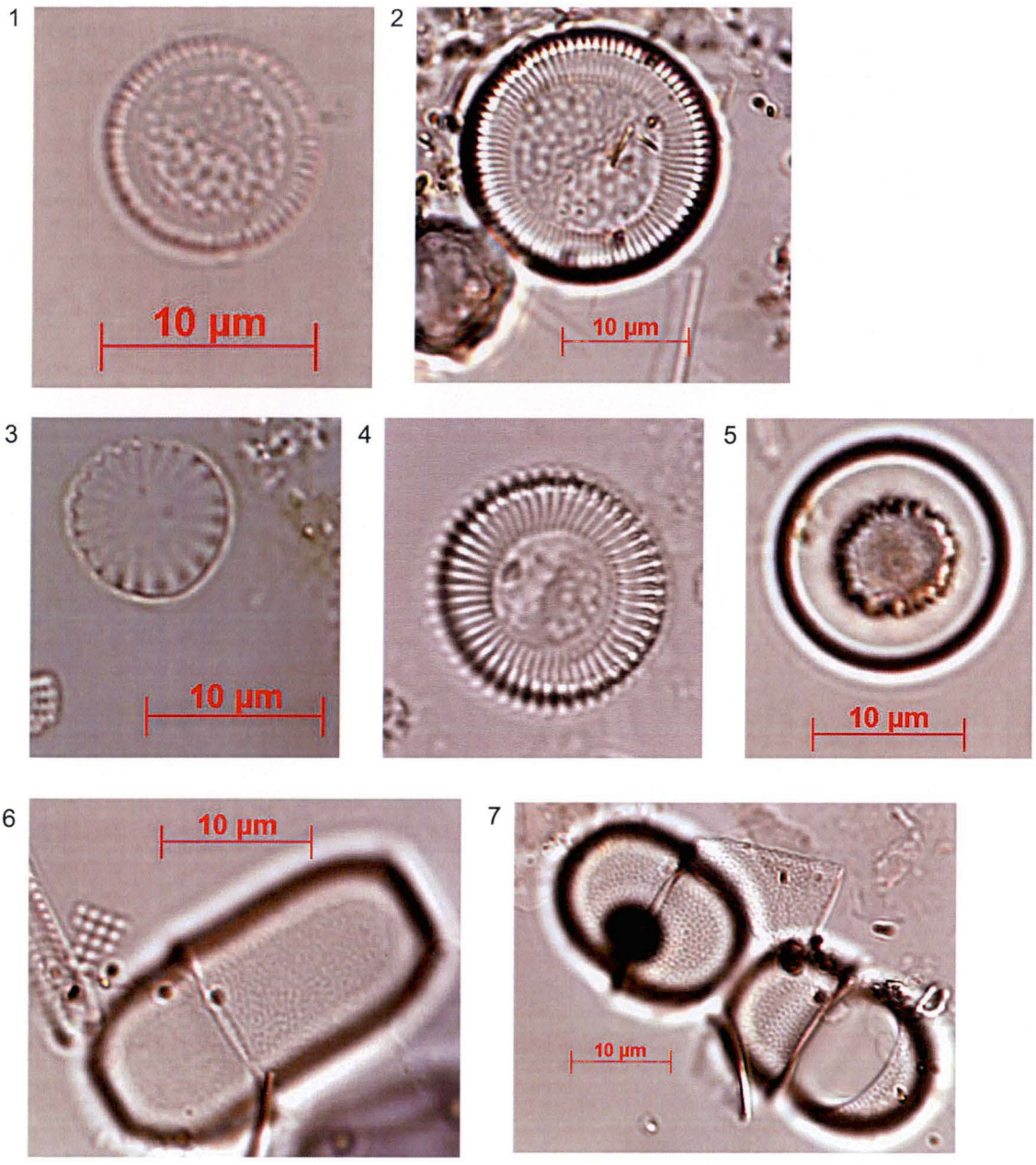
Appendix 3: Tasmanian and Victorian diatom species images

PLATE 1



1. *Actinocyclus* sp. 1
2. *Actinocyclus subtilis* (Gregory) Ralfs in Pritchard
3. *Analulus minutus* Grunow in van Heurck
4. *Aulacoseira pfaffiana* (Reinsch) Krammer
5. *Coscinodiscus centralis* Ehrenberg
6. *Coscinodiscus nitidus* Gregory

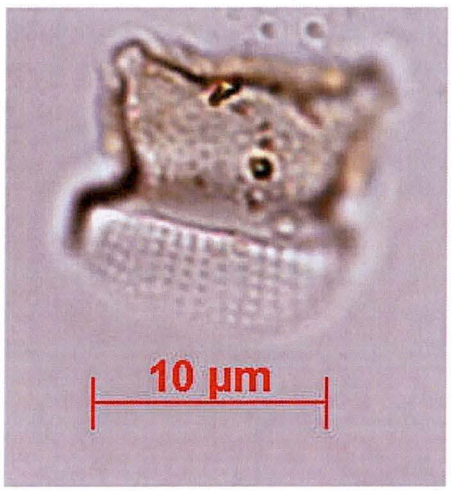
PLATE 2



1-2. *Cyclotella choctawhatcheeana* Prasad
3. *Cyclotella meneghiniana* Kützing
4. *Cyclotella striata* (Kützing) Grunow
5. *Huttoniella reichardtii* (Grunow) Hustedt
5. *Melosira lineata* var. *juergensii* Crawford
7. *Melosira nummuloides* (Dillwyn) Agardh

PLATE 3

1



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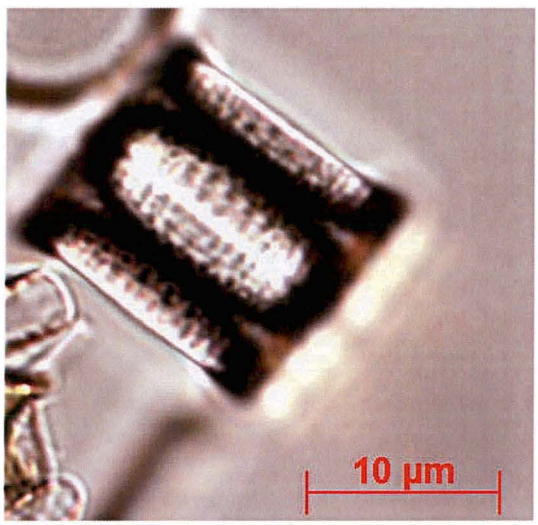
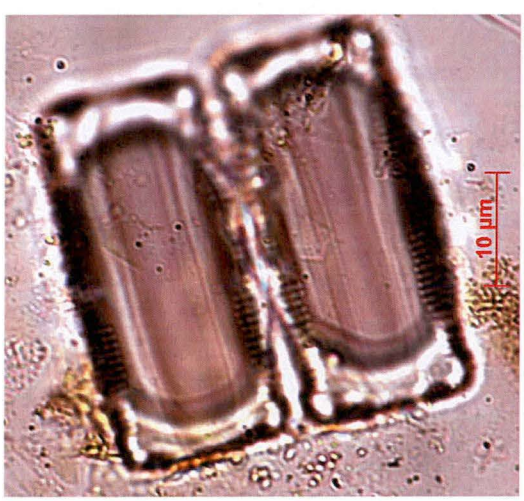
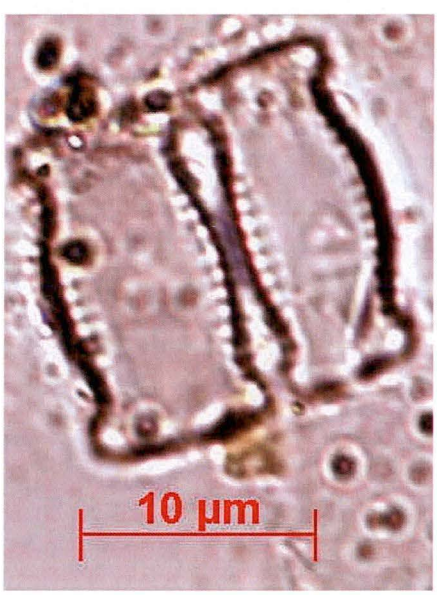


3

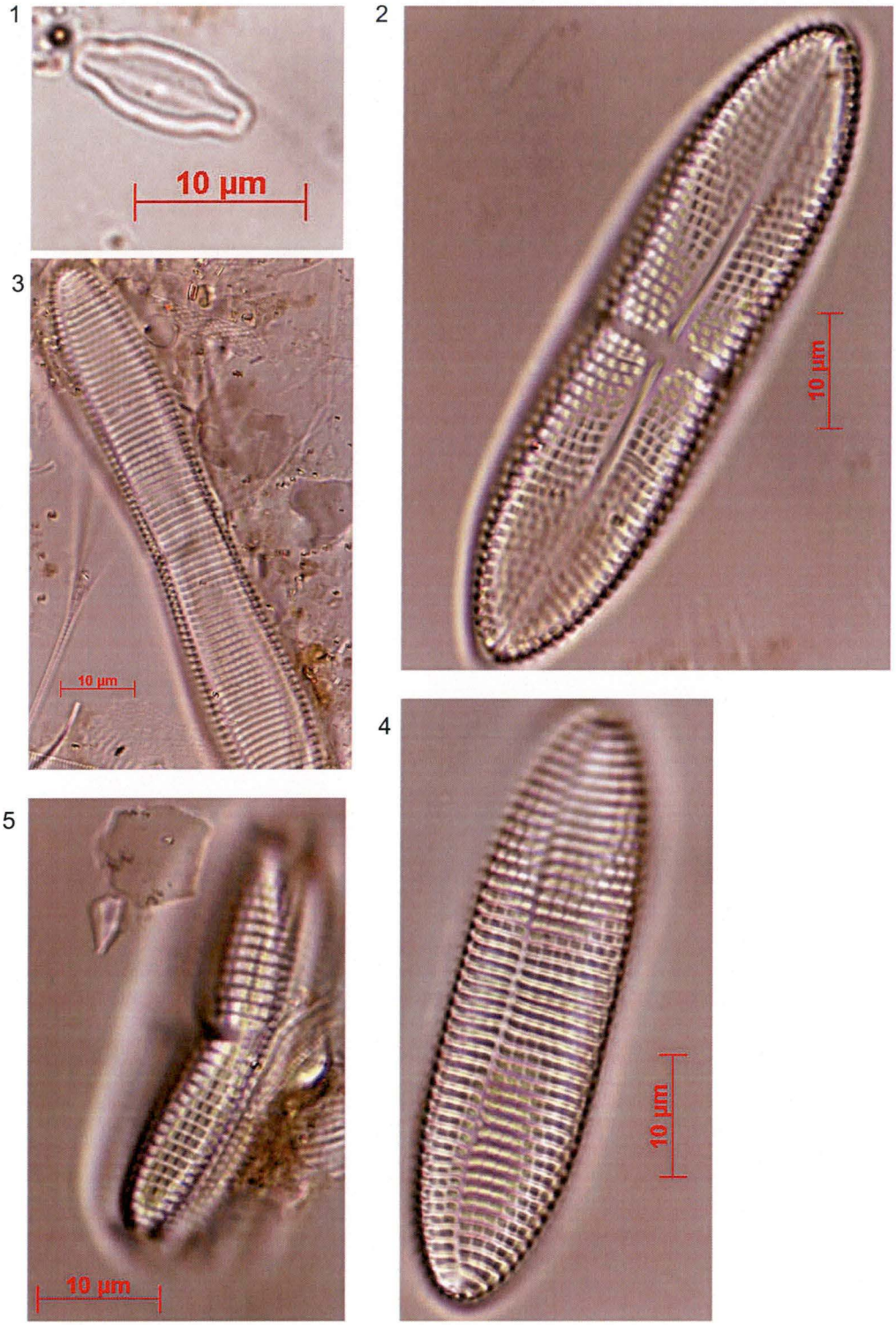


4



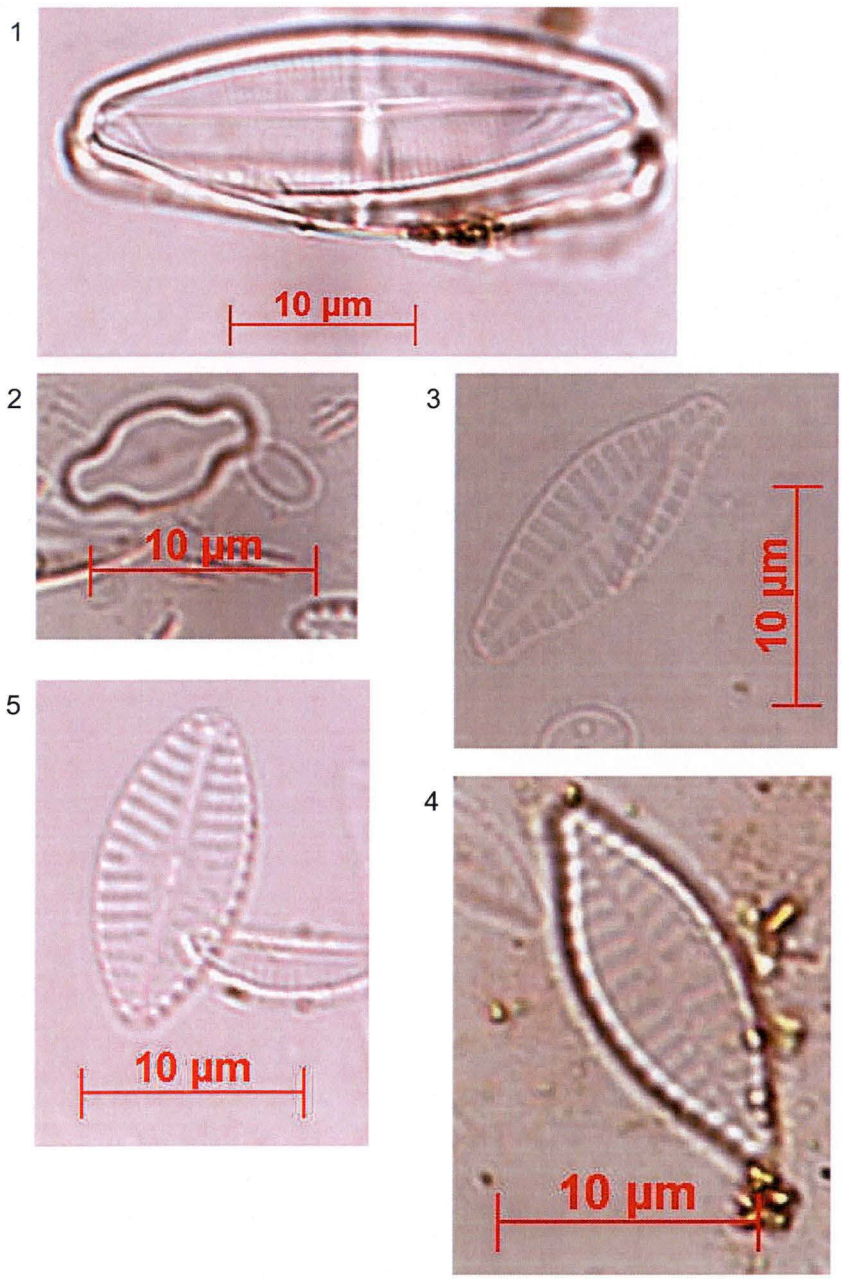
1. *Odontella aurita* (Lyngbye) Agardh
2. *Paralia* sp. 1
3. *Plagiogramma* sp. 1
4. *Plagiogramma* sp. 2

PLATE 4



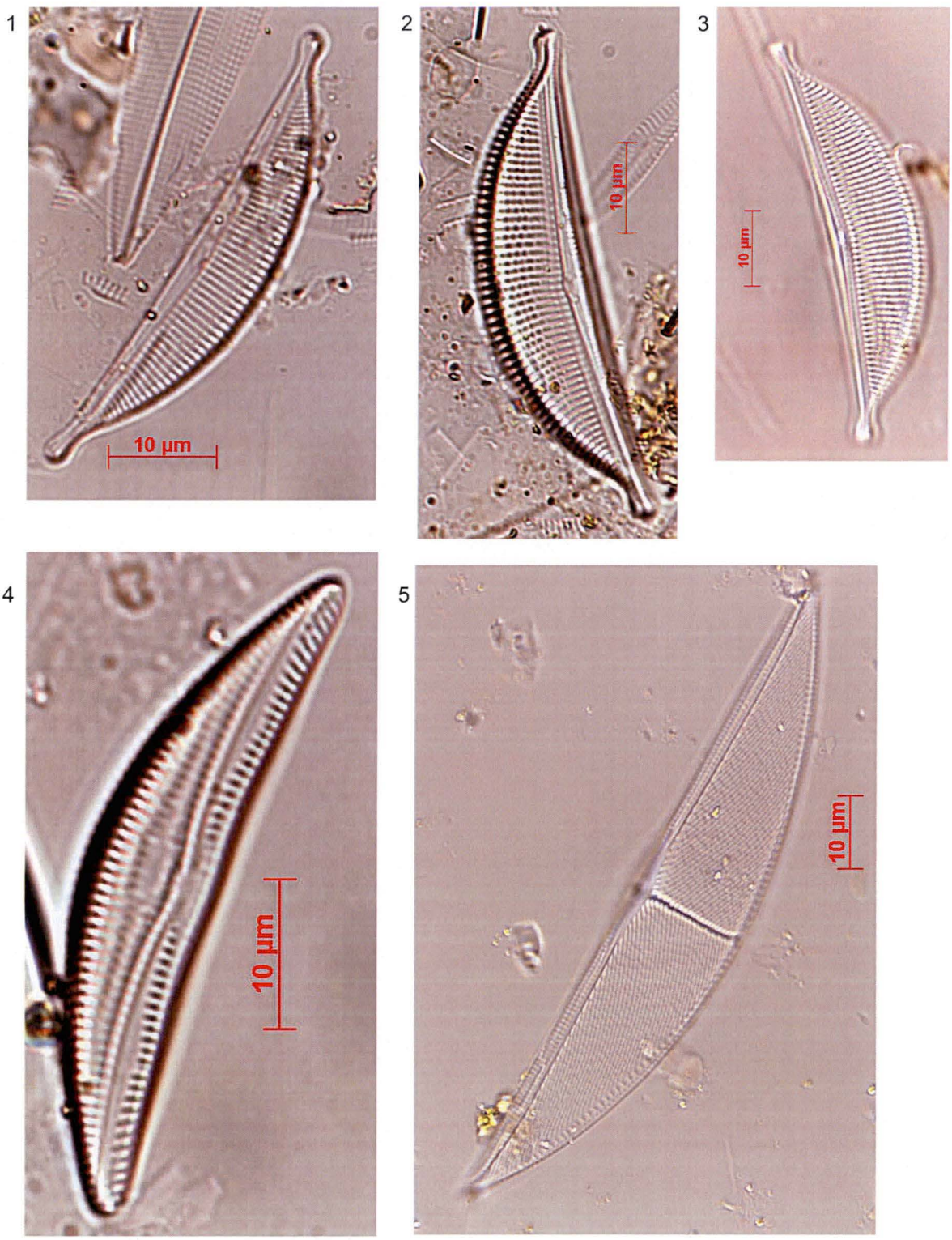
1. *Achnanthes* cf. *amoena* Hustedt
2-3. *Achnanthes brevipes* var. *angustata* Greville
4-5. *Achnanthes brevipes* var. *intermedia* (Küzing) Cleve

PLATE 5



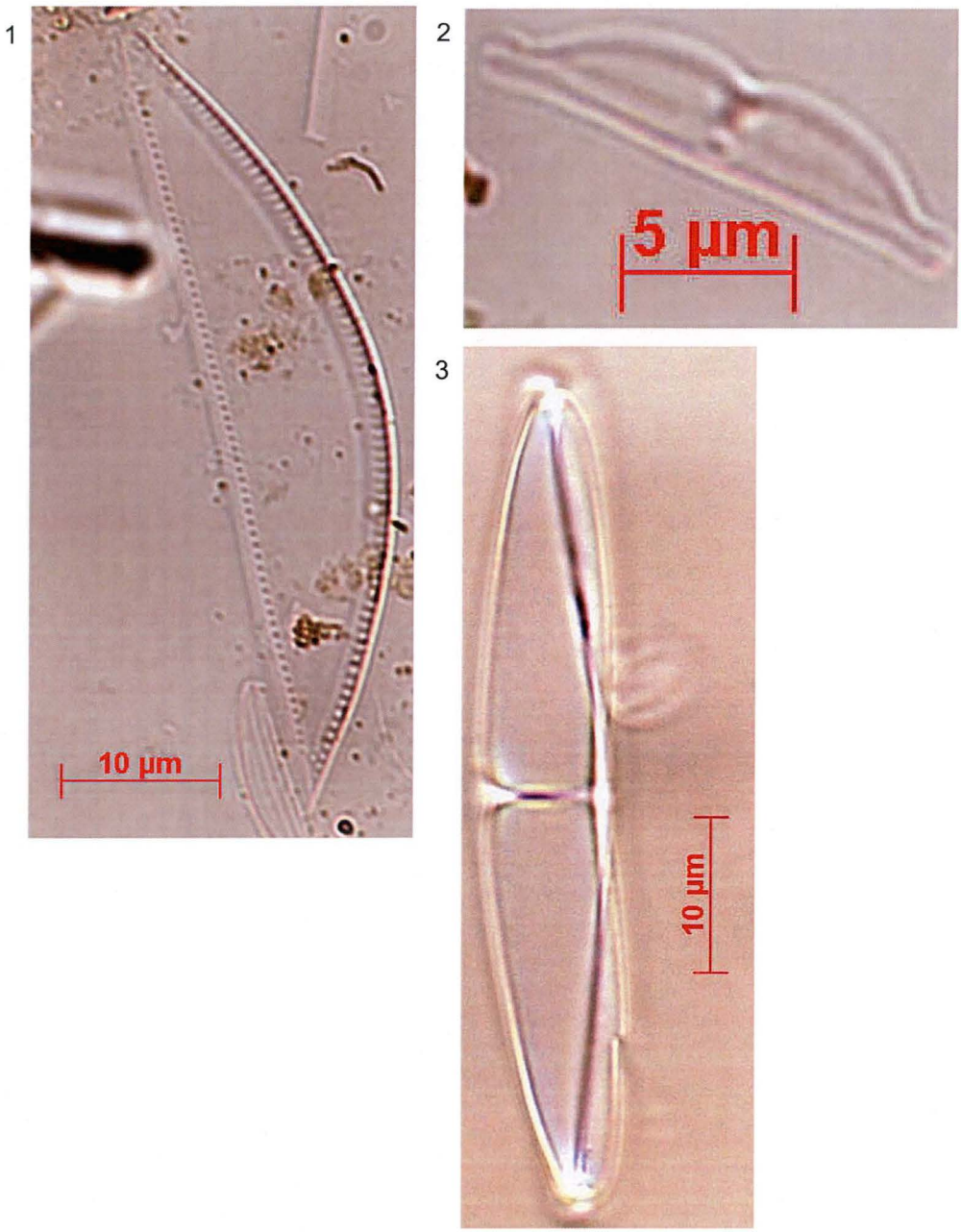
1. *Achnanthes hungarica* (Grunow) Grunow
2. *Achnanthes lemmermannii* Hustedt
3-4. *Achanthes lemmermannii* var. *rostata* Hustedt
5. *Achanthes* sp. 2

PLATE 6



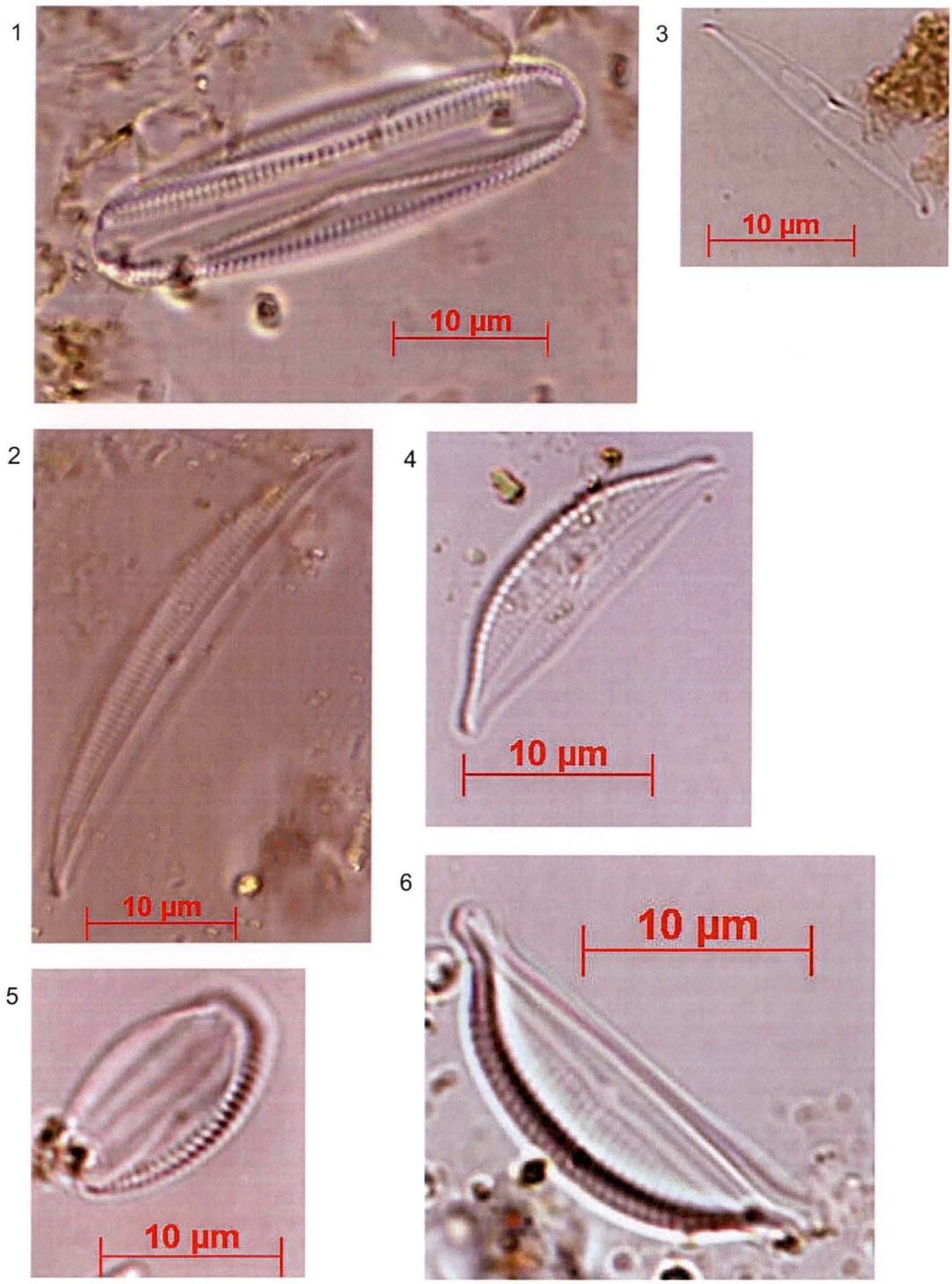
1. *Amphora acutiuscula* Kützing
2-3. *Amphora caroliniana* Giffen
4. *Amphora copulata* (Kützing) Schoeman & Archibald
5. *Amphora decussata* Grunow

PLATE 7



1. *Amphora hyalina* Kützing
2. *Amphora* cf. *kolbei* Aleem
3. *Amphora* cf. *laevissima* Gregory

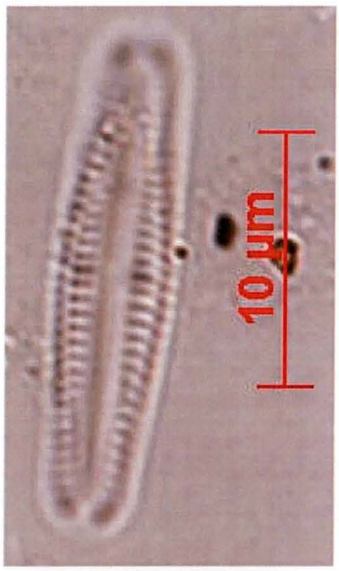
PLATE 8



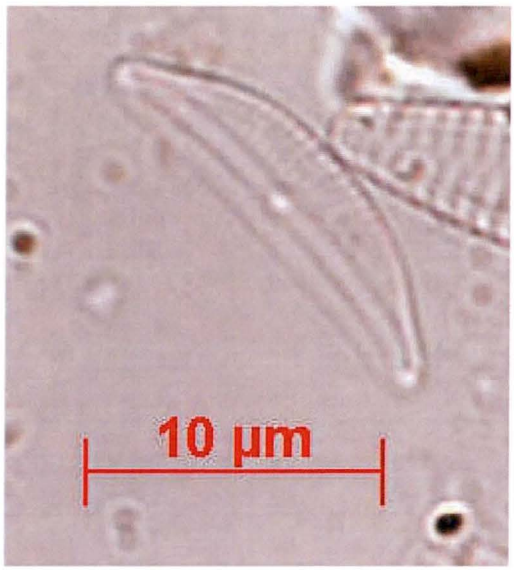
1-2. *Amphora* cf. *luciae* Cholnoky
3. *Amphora* cf. *staurophora* Juhlin-Dannfelt
4. *Amphora* sp. 1
5. *Amphora* sp. 2
6. *Amphora* sp. 3

PLATE 9

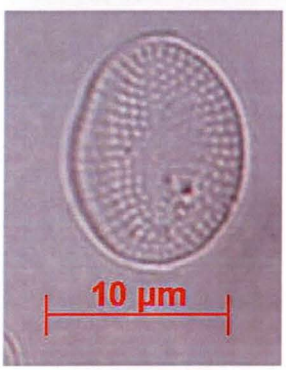
1



2



3



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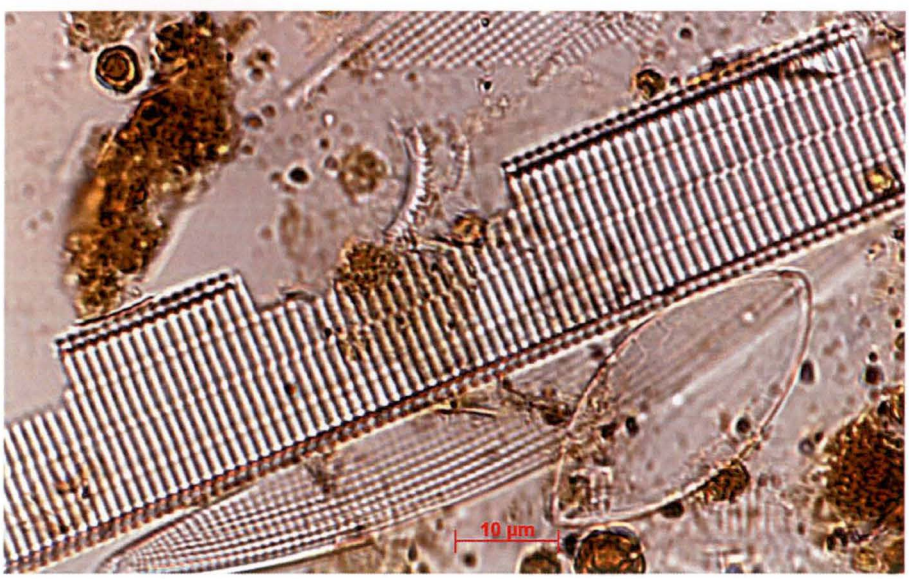
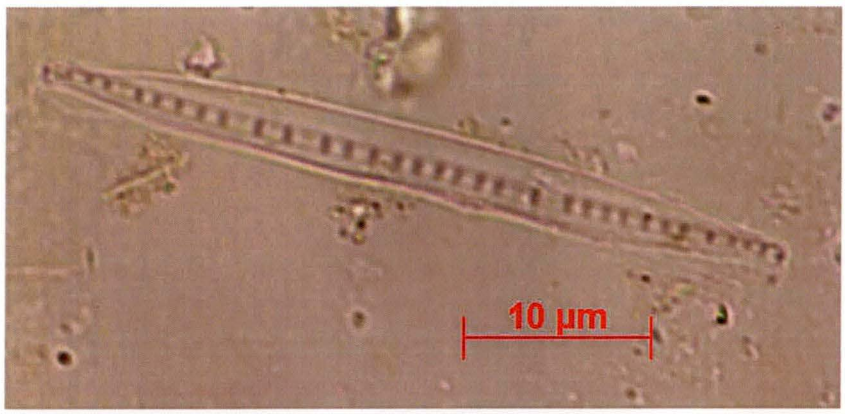
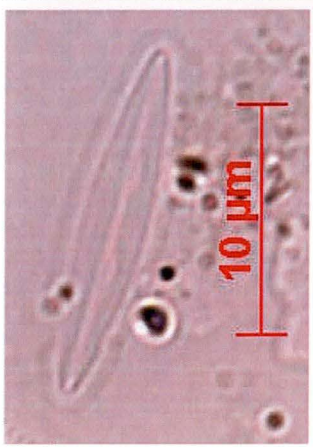
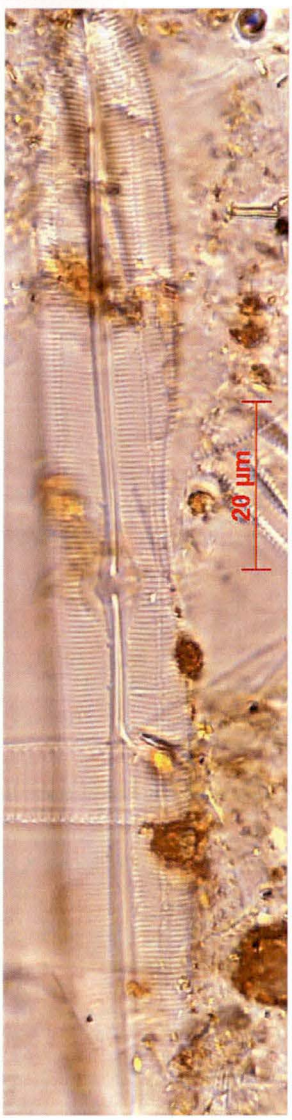


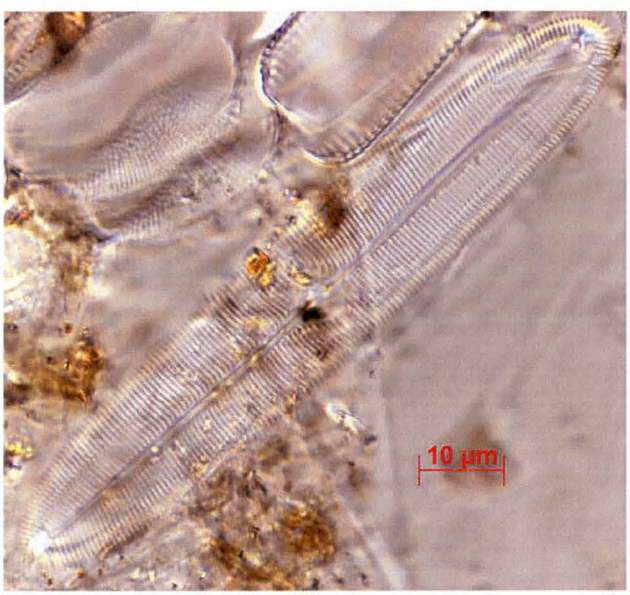
1. *Amphora* sp. 4
2. *Amphora* sp. 5
3. *Anorthoneis vortex* Sterrenburg
4. *Ardissonia formosa* (Hantzsch) Grunow

PLATE 10



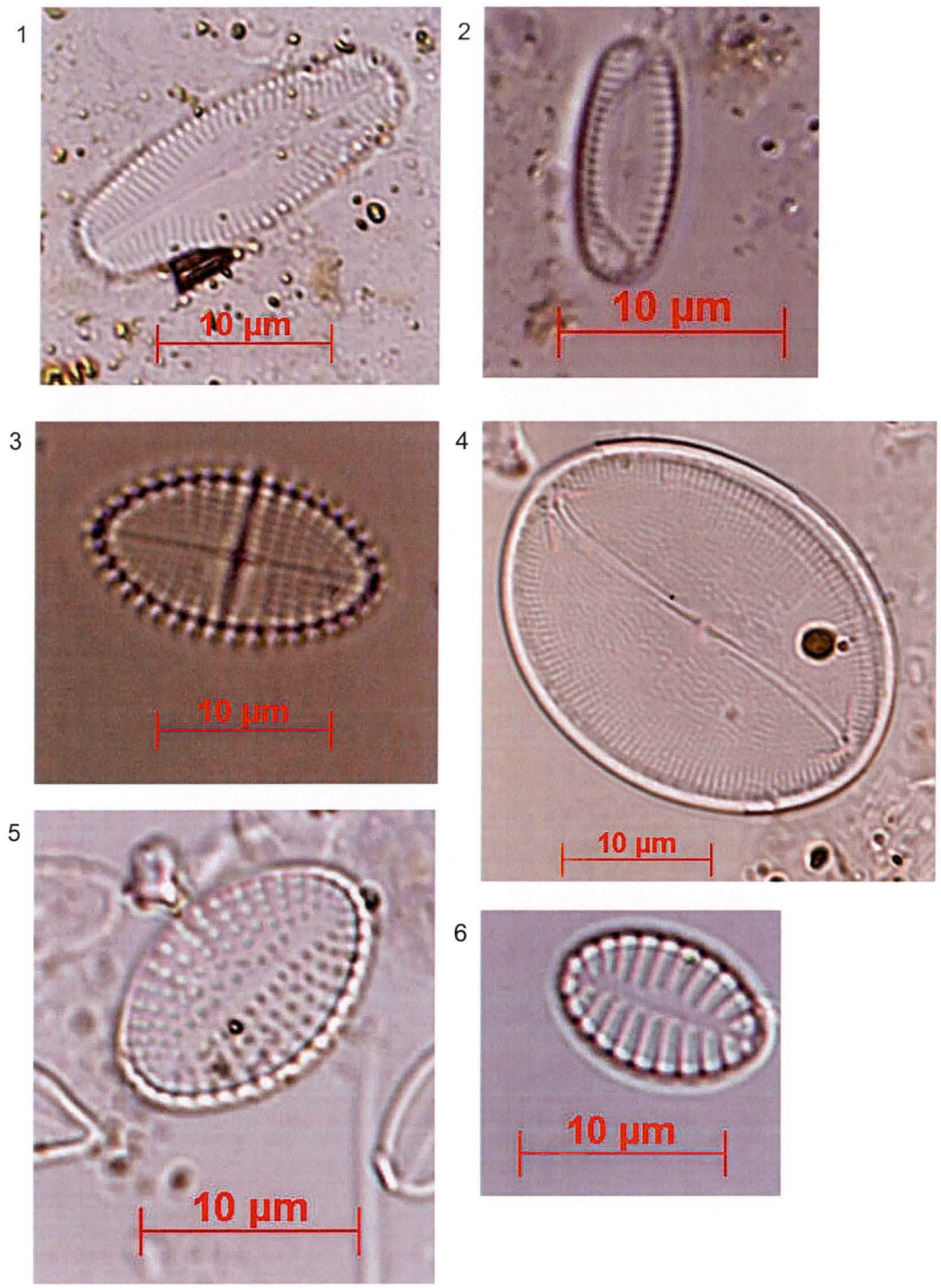






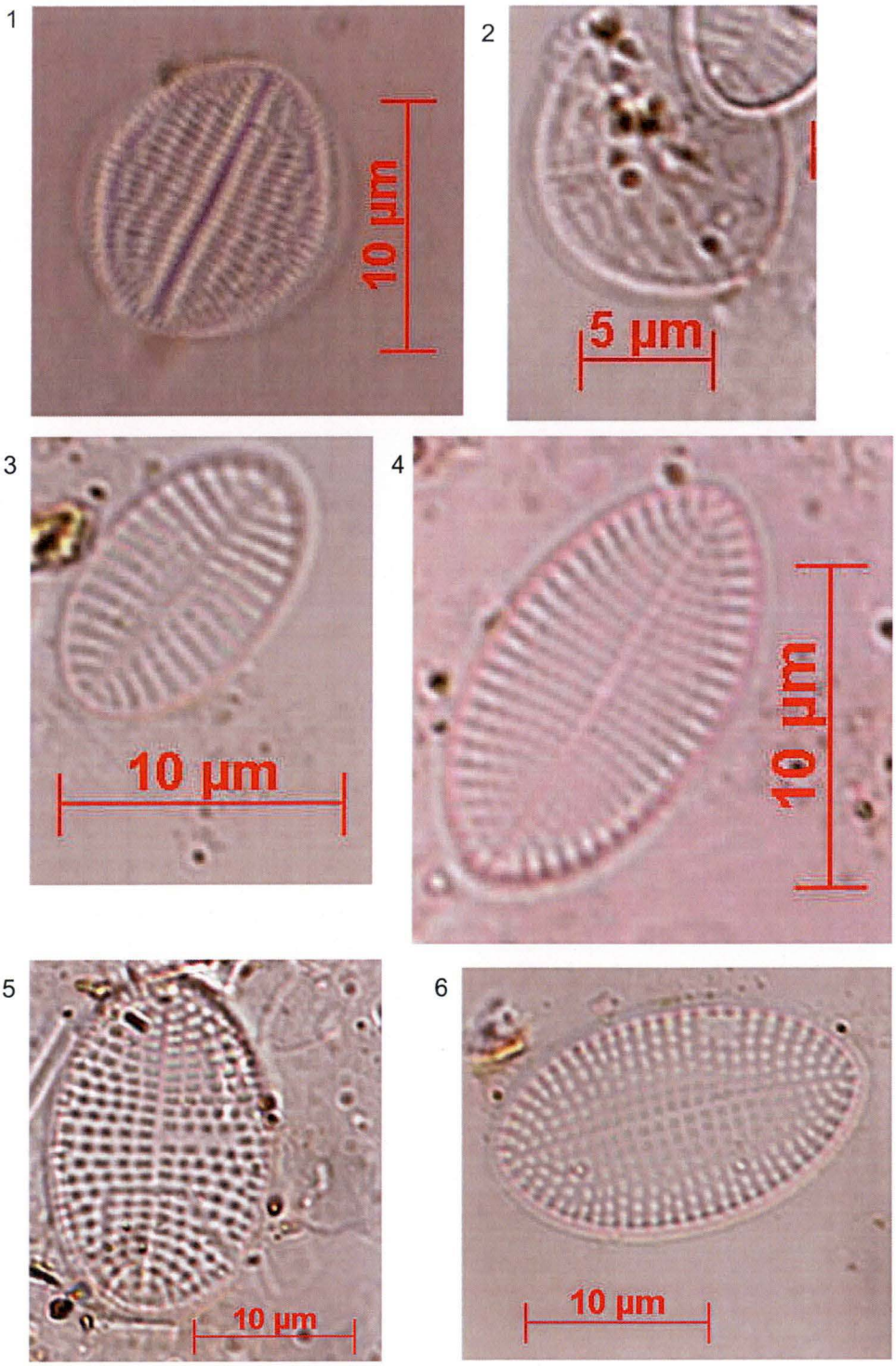
1. *Bacillaria paxillifer* (O.F. Müller) Hendey
2. *Berkeleya* sp. 1
3. *Biremis lucens* (Hustedt) Sabbe & Vyverman
4. *Caloneis elongata* (Grunow) Cleve

PLATE 11



1. *Chamaepinnularia* cf. *clamans* (Hustedt) Witkowski
2. *Chamaepinnularia* cf. *truncata* (König) Witkowski
3. *Cocconeis costata* Gregory
4. *Cocconeis krammeri* Lange-Bertalot & Metzeltin
5. *Cocconeis neodiminuta* Krammer
6. *Cocconeis* cf. *pinnata* Gregory in Greville

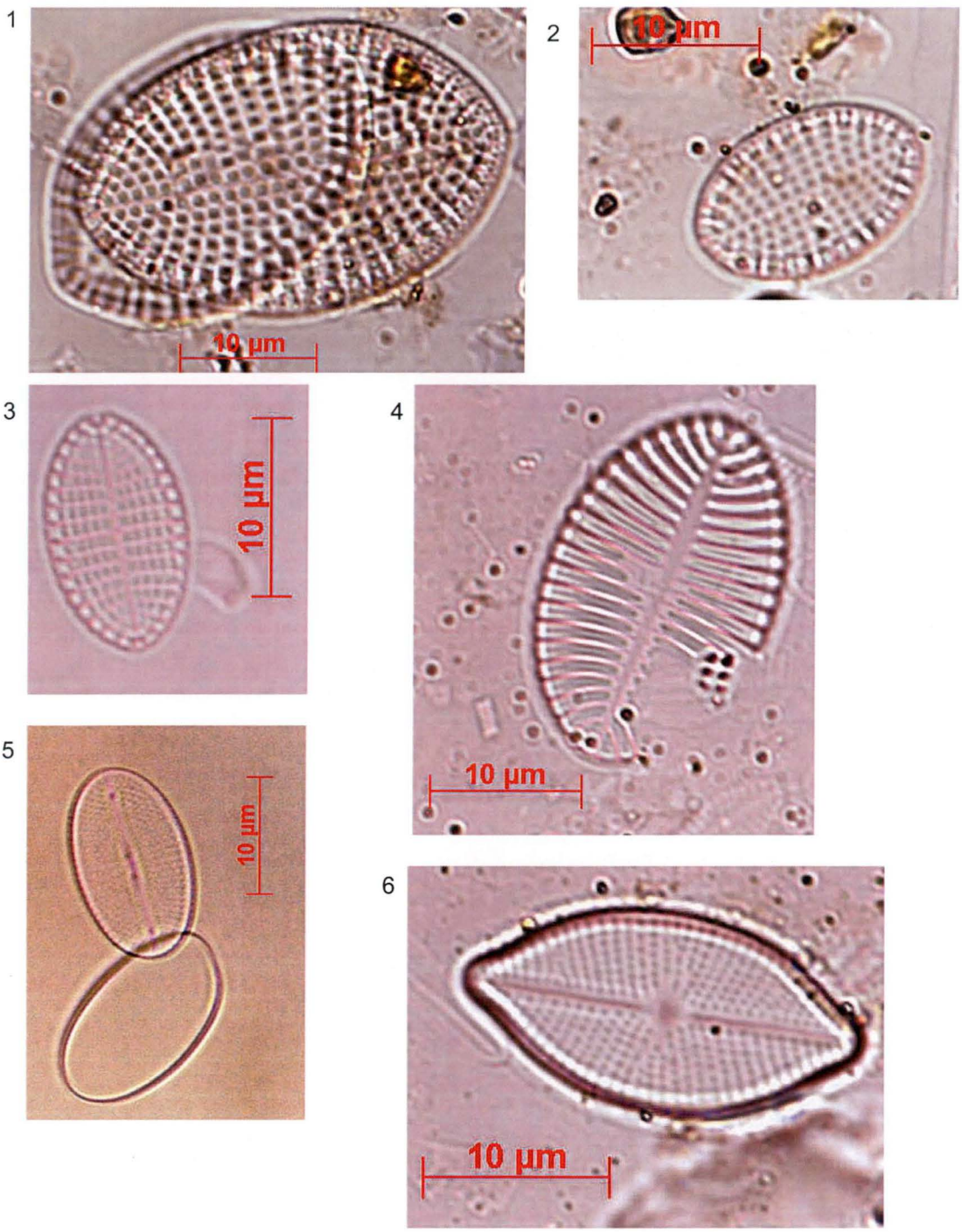
PLATE 12



1. *Cocconeis pediculus* Kützing
2. *Cocconeis pediculus* var. 1
3. *Cocconeis peltoides* Hustedt
4. *Cocconeis placentula* Ehrenberg

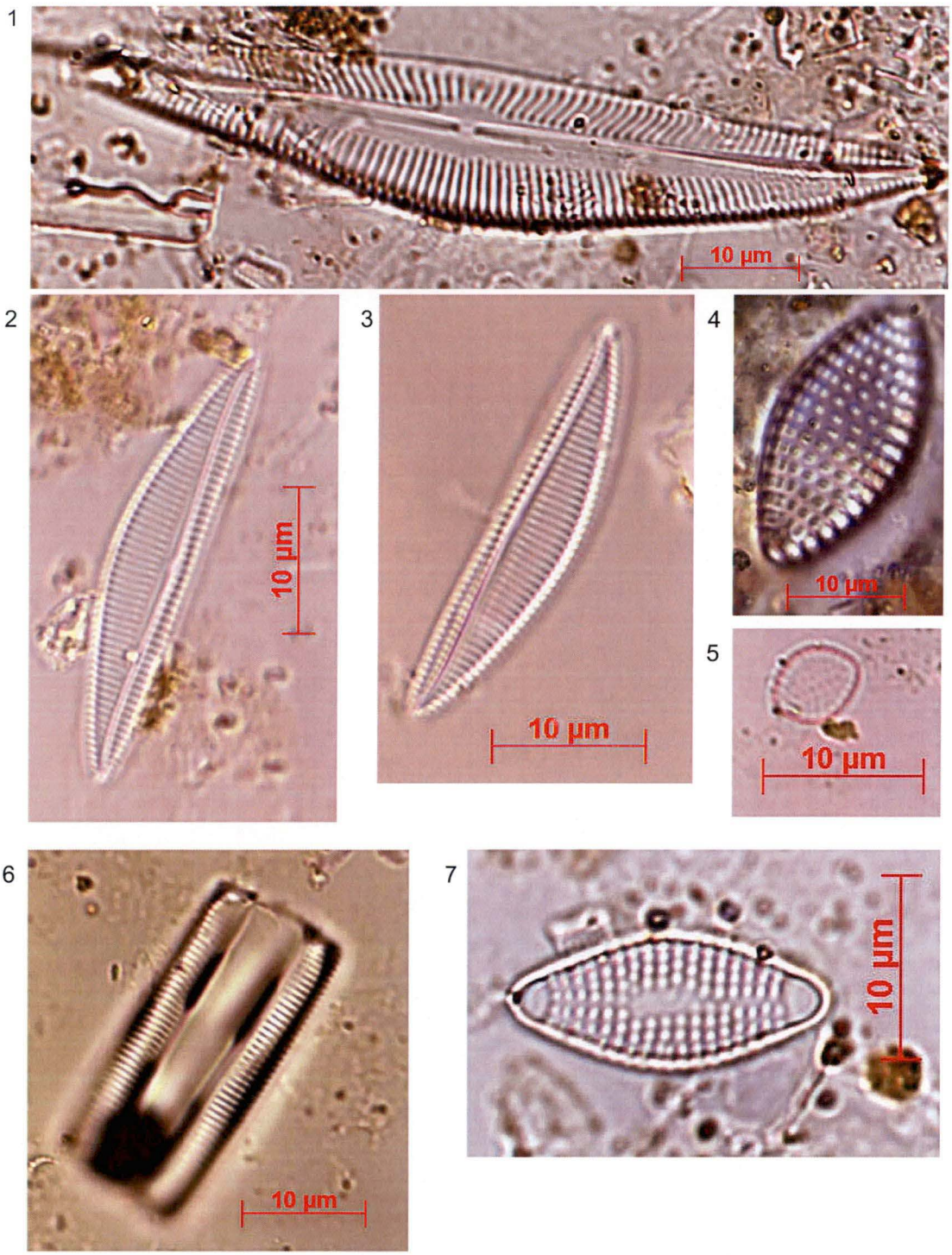
5-6. *Cocconeis placentula* var. *euglypta* (Ehrenberg) Cleve

PLATE 13



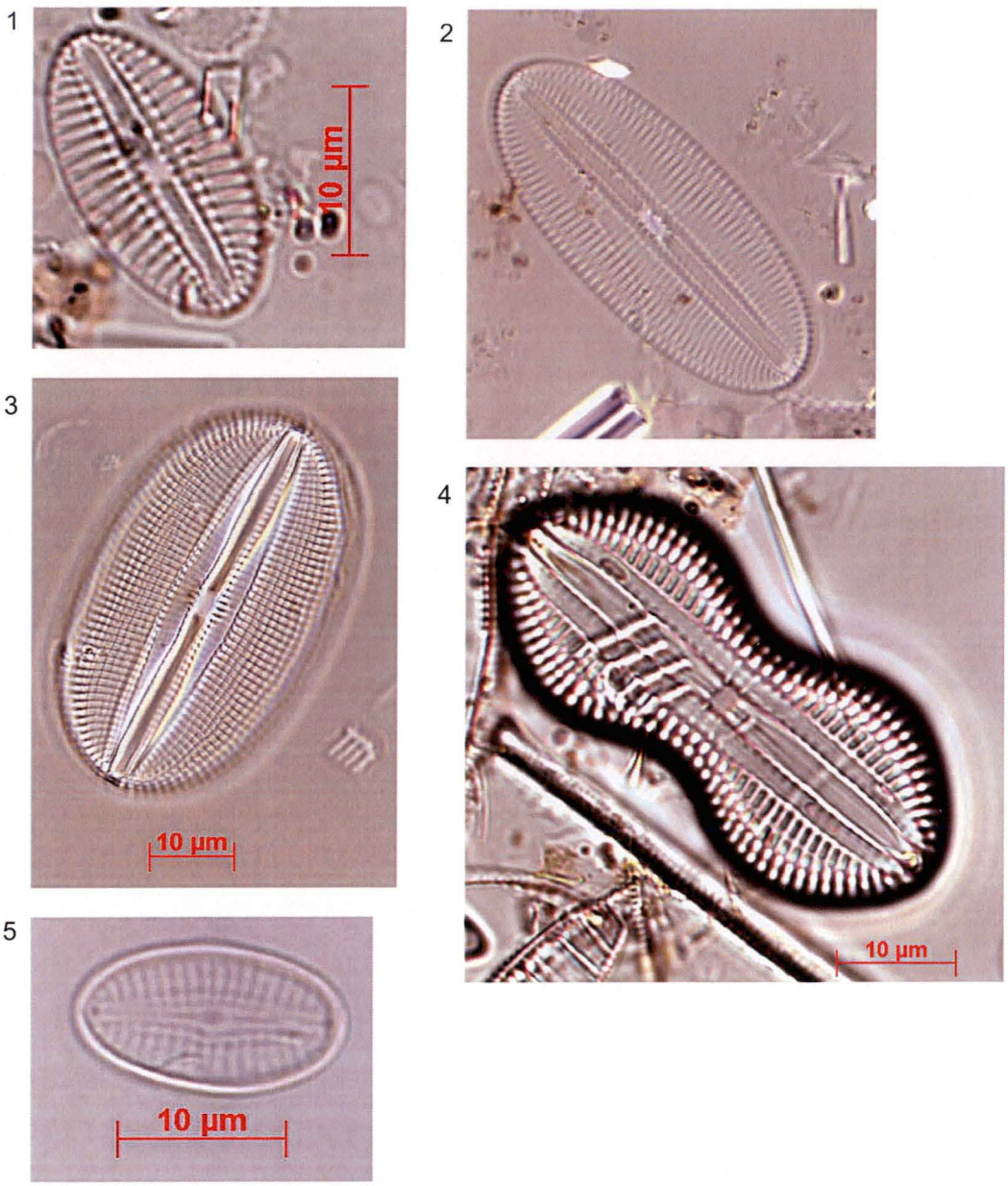
1. *Cocconeis scutellum* Ehrenberg
2. *Cocconeis scutellum* var. 1
3. *Cocconeis scutellum* var. *parva* Grunow
4. *Cocconeis* sp. 1
5. *Cocconeis* sp. 2
6. *Cosmioneis* cf. *pusilla* (W. Smith) D.G. Mann & A.J. Stickle

PLATE 14



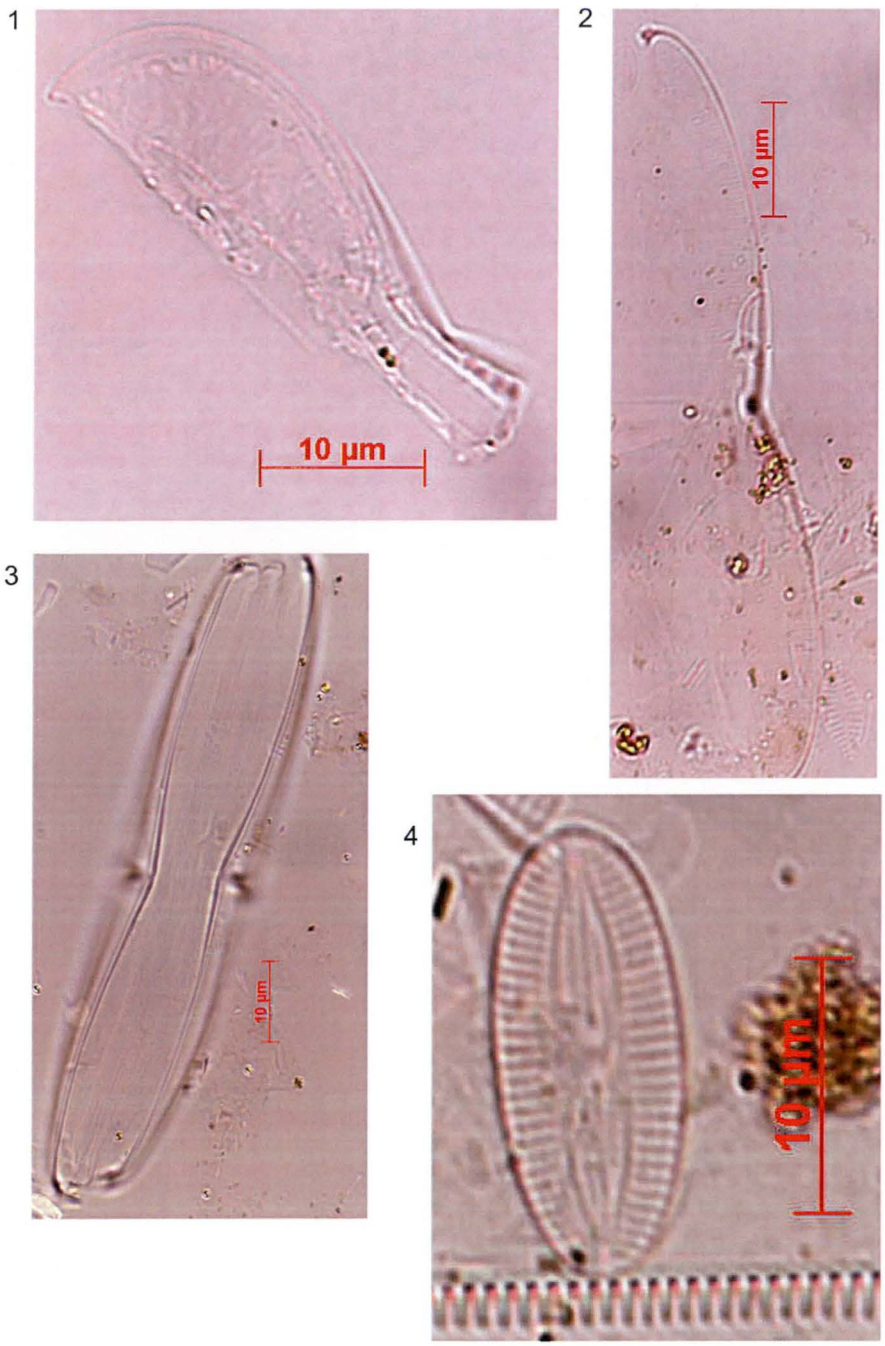
1. *Cymbella* sp. 1
2. *Cymbella* sp. 2
3. *Delphineis* sp. 1
4. *Delphineis minutissima* (Hustedt) Simonsen
5. *Diatomella* cf. *balfouriana* Greville
7. *Dimeregramma minor* var. *nana* (Gregory) Van Heurck

PLATE 15



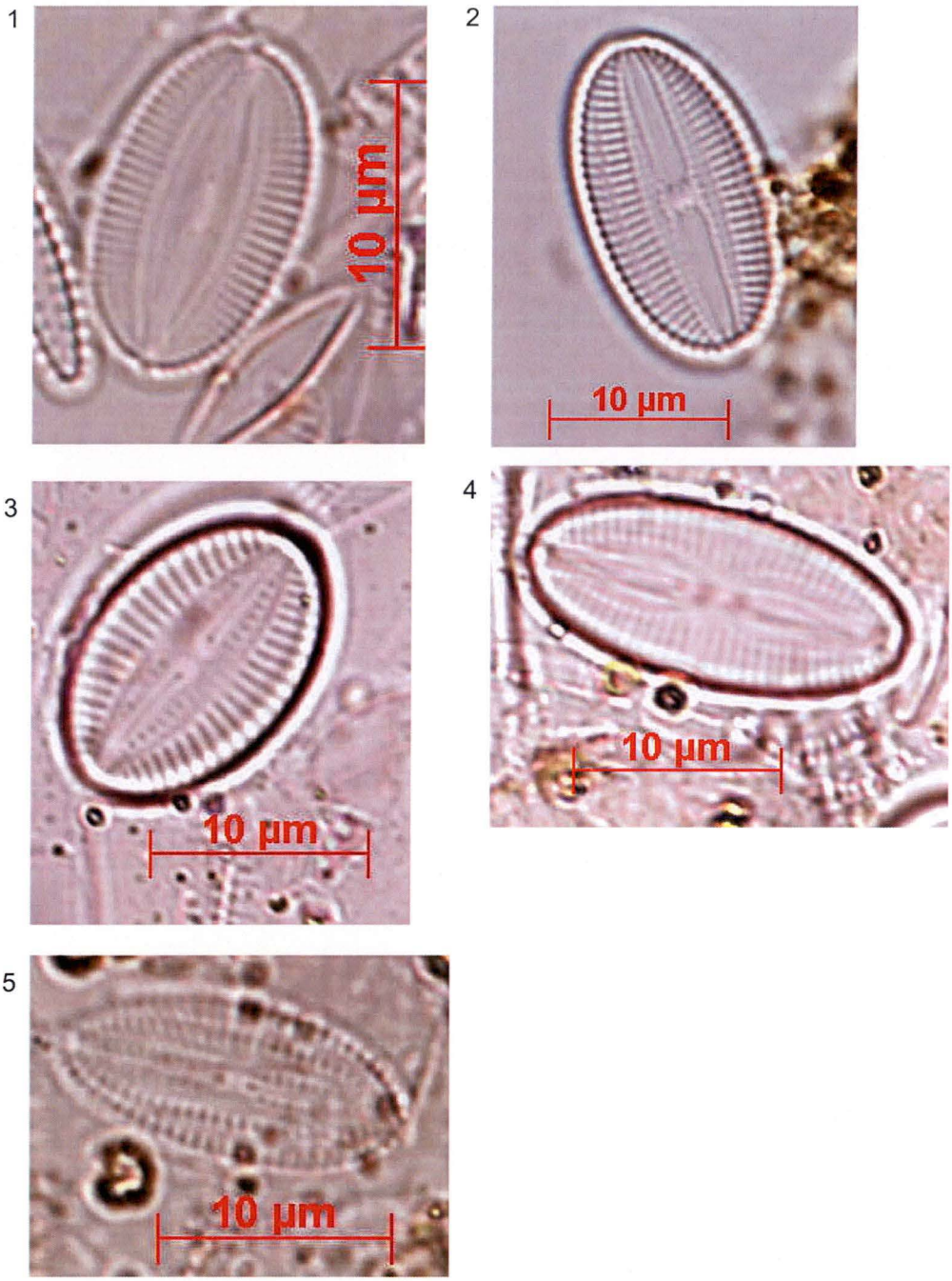
1. *Diploneis* cf. *decipiens* var. *parallela* Cleve
2. *Diploneis* cf. *litoralis* (Donkin) Cleve
3. *Diploneis* cf. *marginestriata* Hustedt
4. *Diploneis stroemii* Hustedt
5. *Diploneis* sp. 1

PLATE 16



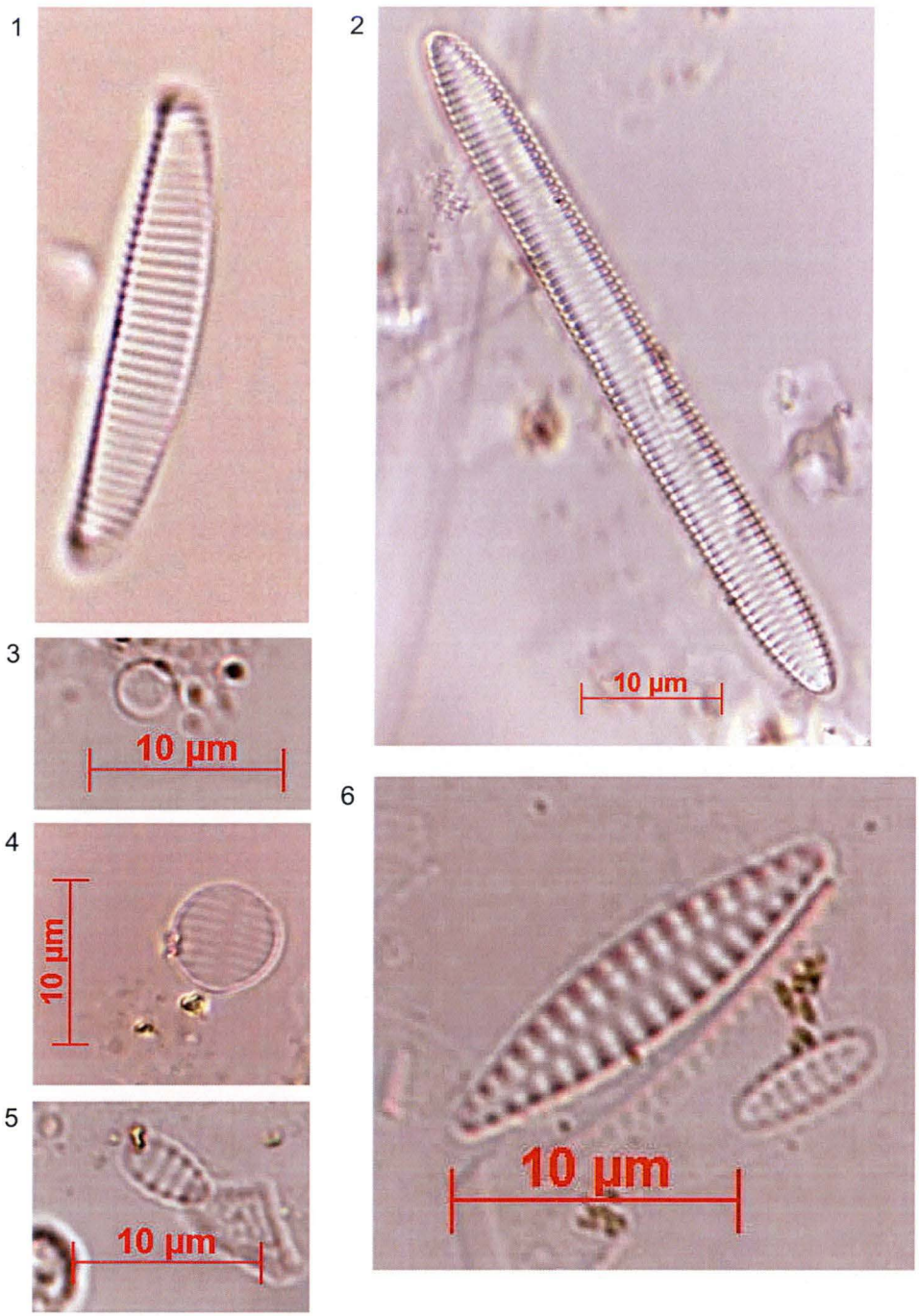
1-2. *Entomoneis alata* (Ehrenberg) Ehrenberg
3. *Entomoneis kjellmanii* (Cleve) Poulin & Cardinal
4. *Fallacia* cf. *litoricola* (Hustedt) D.G. Mann

PLATE 17



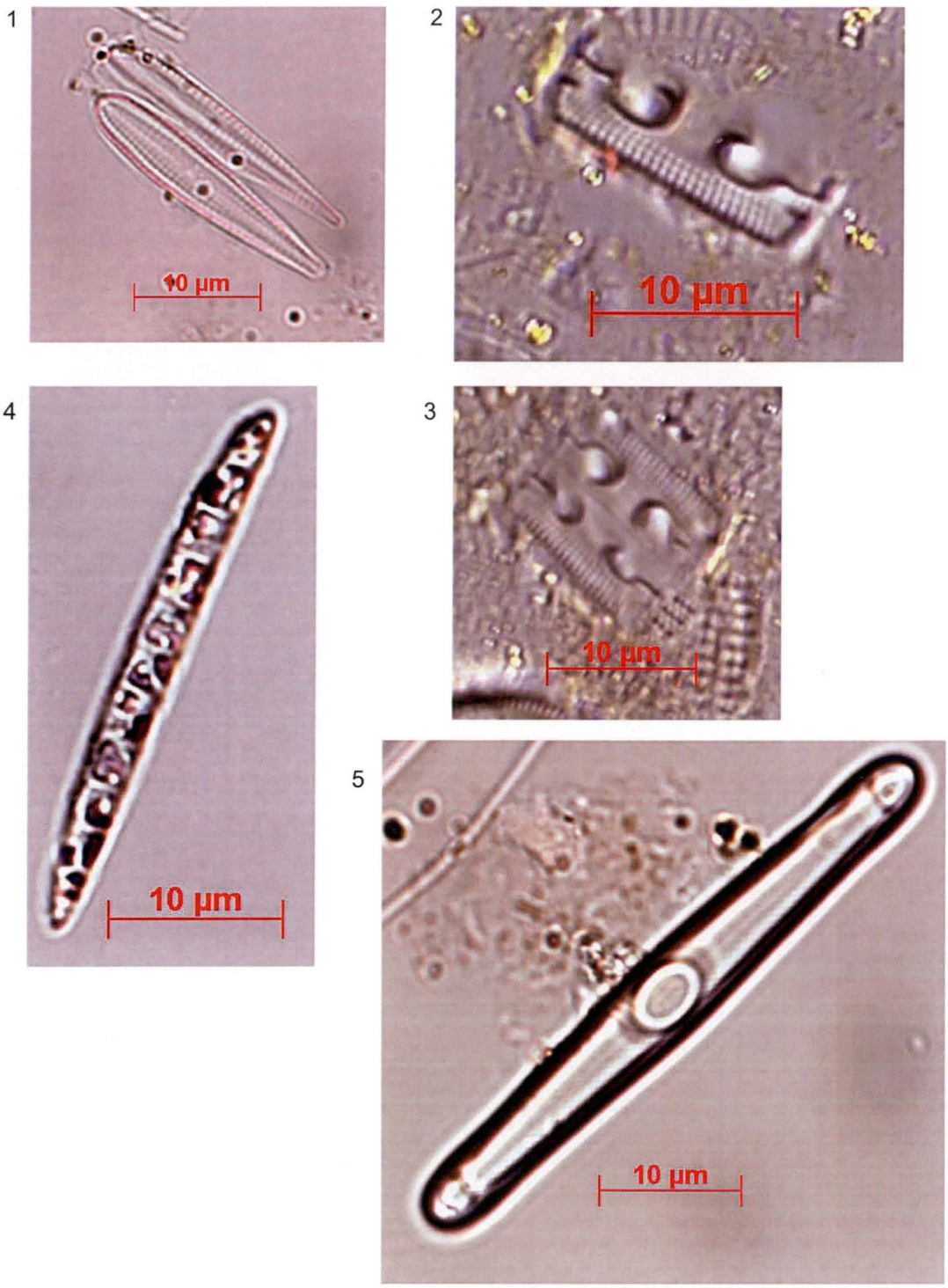
1. *Fallacia florinae* (Möller) Witkowski
2. *Fallacia pseudony* (Hustedt) D.G. Mann
3. *Fallacia* cf. *oculiformis* (Hustedt) D.G. Mann
4. *Fallacia subforcipata* (Hustedt) Mann
5. *Fallacia tenera* (Hustedt) D.G. Mann

PLATE 18



1. *Fragilaria* cf. *binalis* Ehrenberg
2. *Fragilaria capucina* Desmazières
3. *Fragilaria elliptica* Schumann
4. *Fragilaria elliptica* var. 1
5. *Fragilaria geocollegarum* Witkowski & Lange-Bertalot
6. *Fragilaria pinnata* Ehrenberg

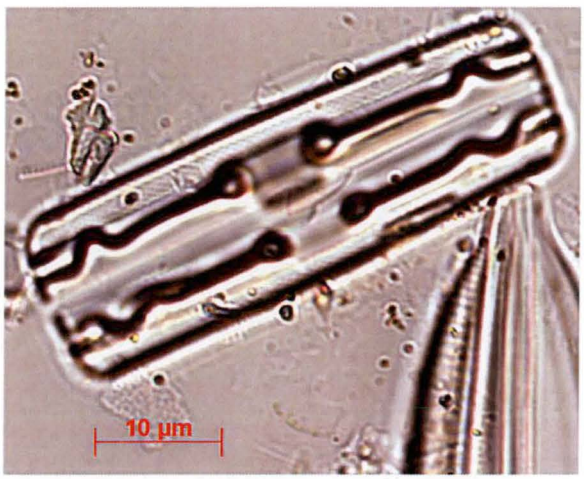
PLATE 19



1. *Gomphonema* sp. 1
2-3. *Grammatophora angulosa* Ehrenberg
4. *Grammatophora arcuata* Ehrenberg
5. *Grammatophora macilenta* W. Smith

PLATE 20

1



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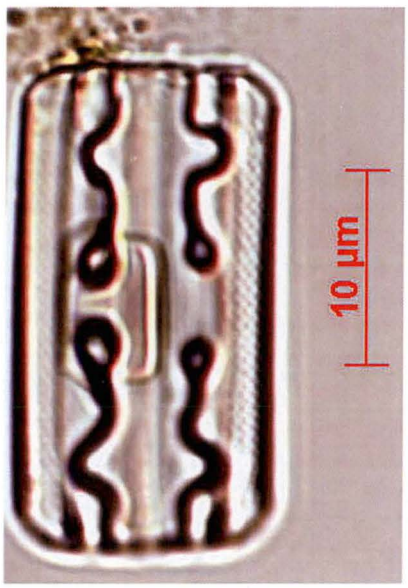

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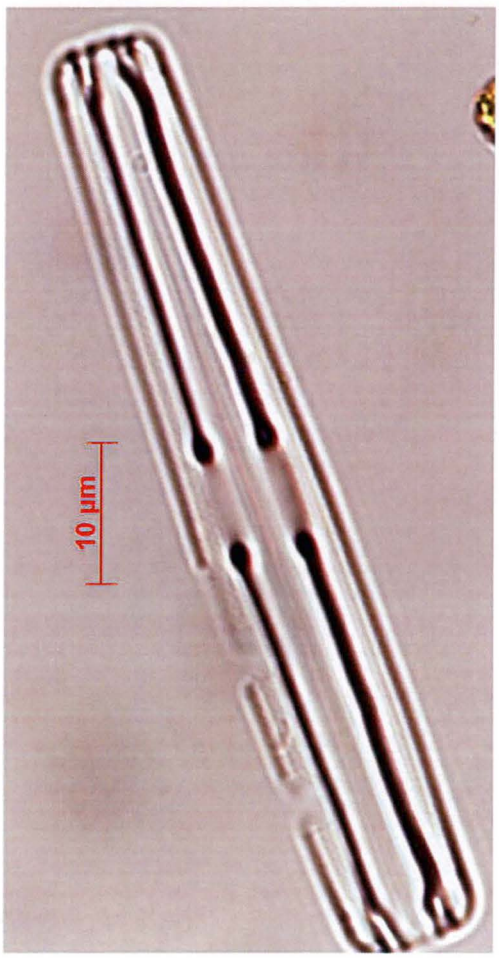
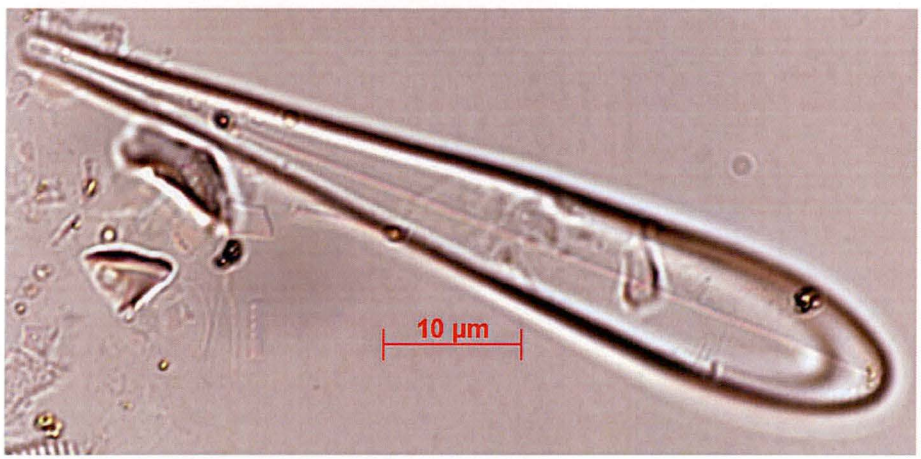


1. *Grammatophora marina* (Lyngbye) Kützing
2. *Grammatophora oceania* Ehrenberg
3. *Grammatophora subtilissima* Bailey

PLATE 21

1

2



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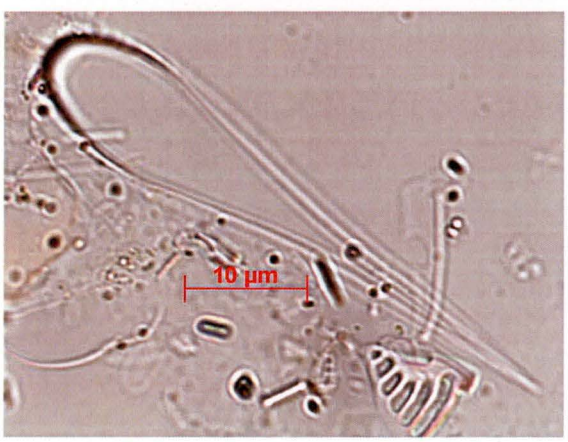
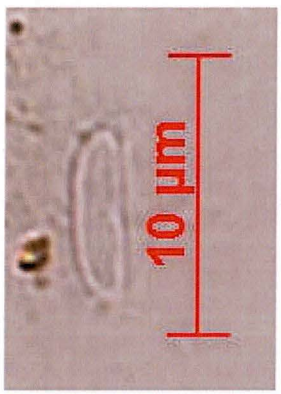


1. *Gyrosigma balticum* (Ehrenberg) Rabenhorst
2. *Licmophora* cf. *debilis* (Kutzing) Grunow ex Van Heurck
3. *Licmophora* sp. 1

PLATE 22

1



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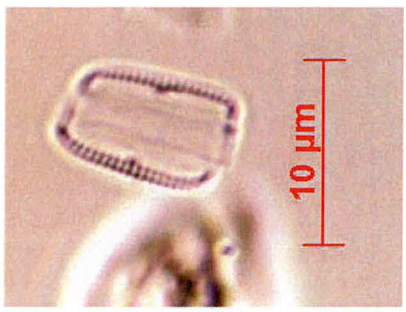

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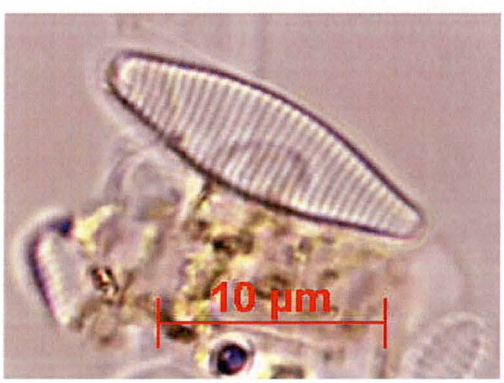
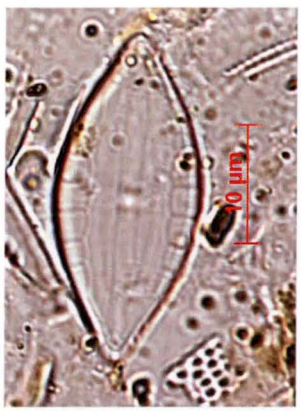


1. *Lunella* cf. *bisecta* Snoeijs
2. *Lunella* cf. *bisecta* var. 1
3. *Lyrella amphoroides* D.G. Mann
4. *Martyana* cf. *schulzii* (Brockmann) Snoeijs

PLATE 23

1



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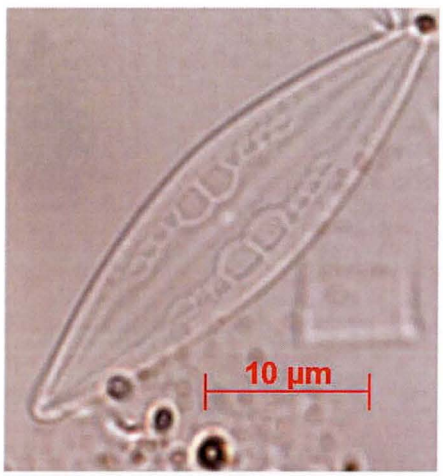

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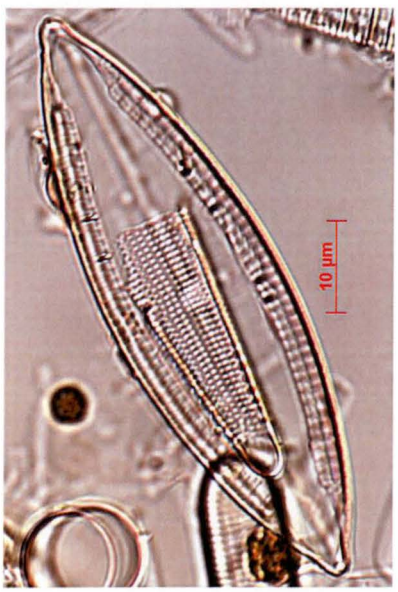

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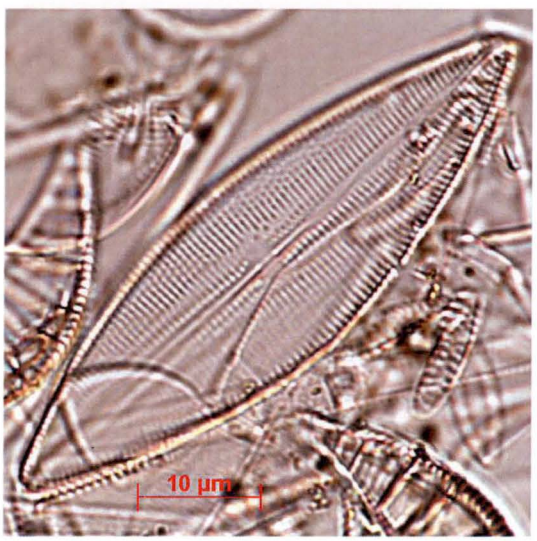

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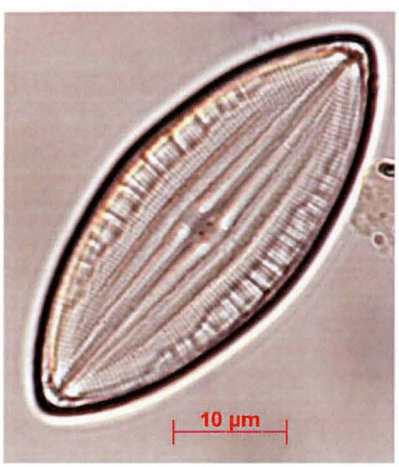
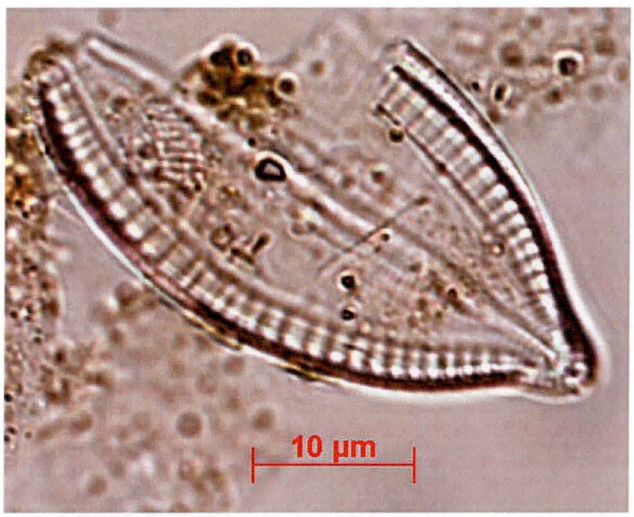


1. *Mastogloia baldjikiana* Grunow
2. *Mastogloia exilis* Hustedt
3-4. *Mastogloia braunii* Grunow
5. *Mastogloia mauritiana* Brun

PLATE 24

1



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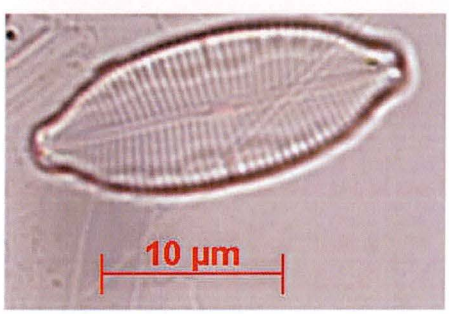

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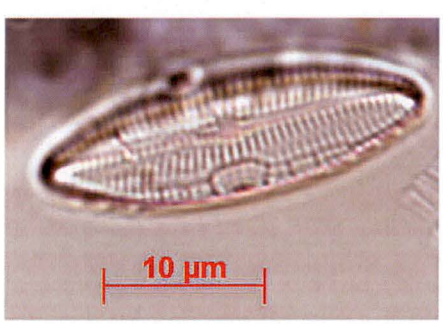

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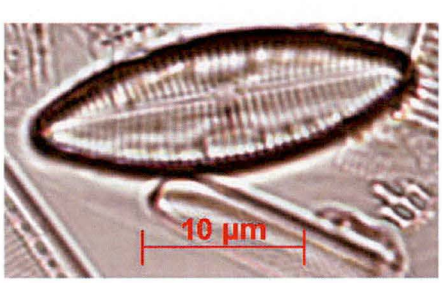

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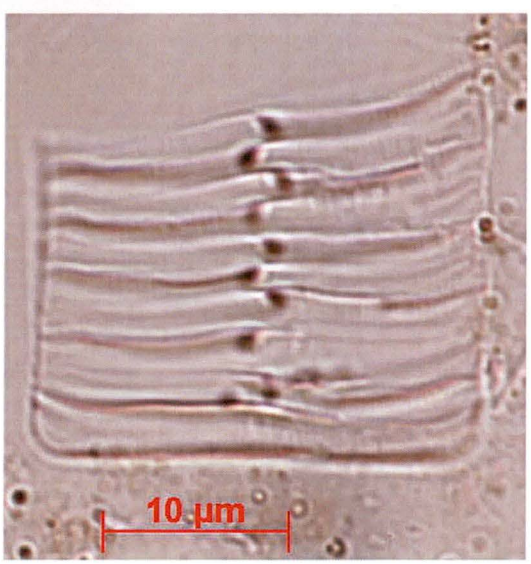
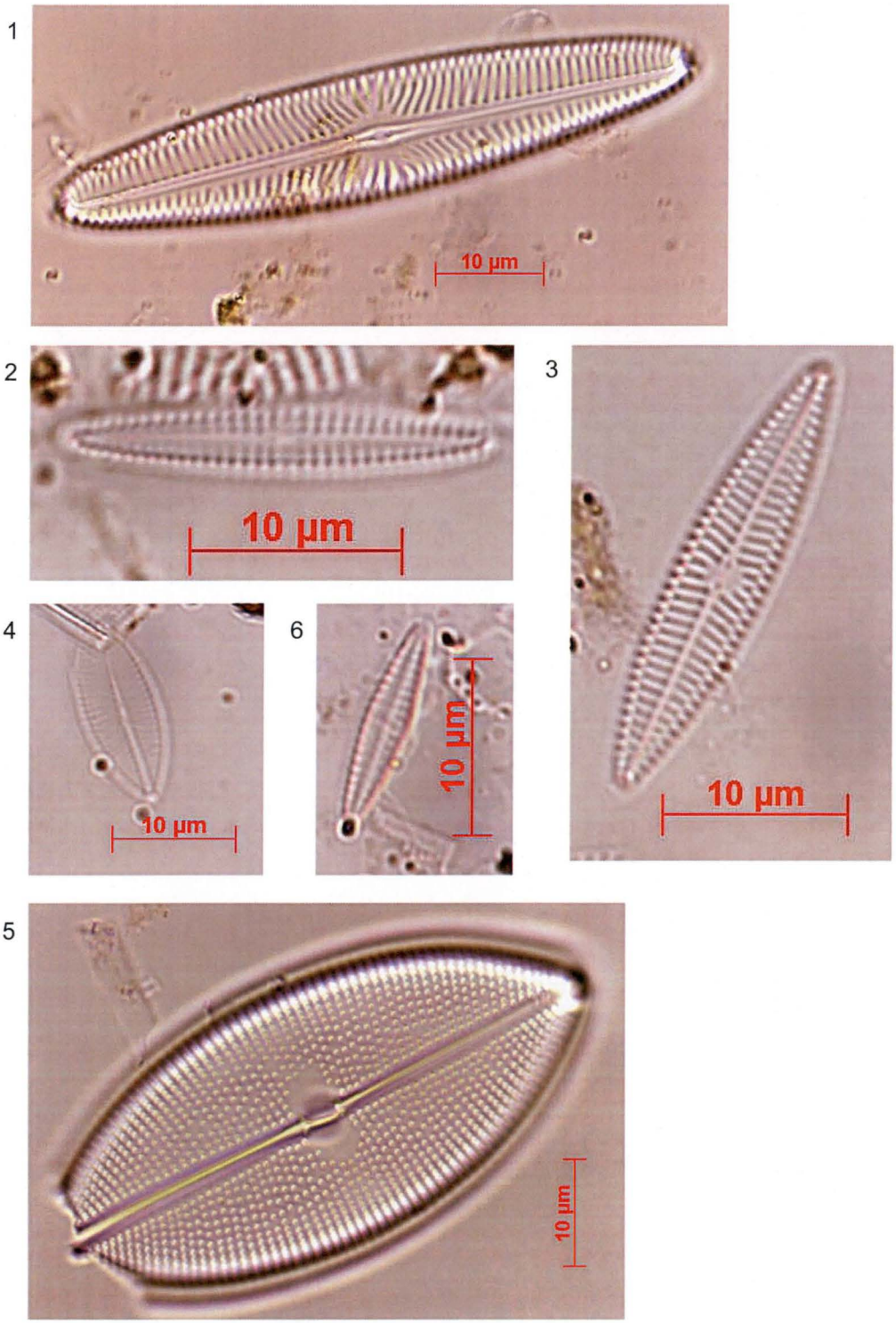


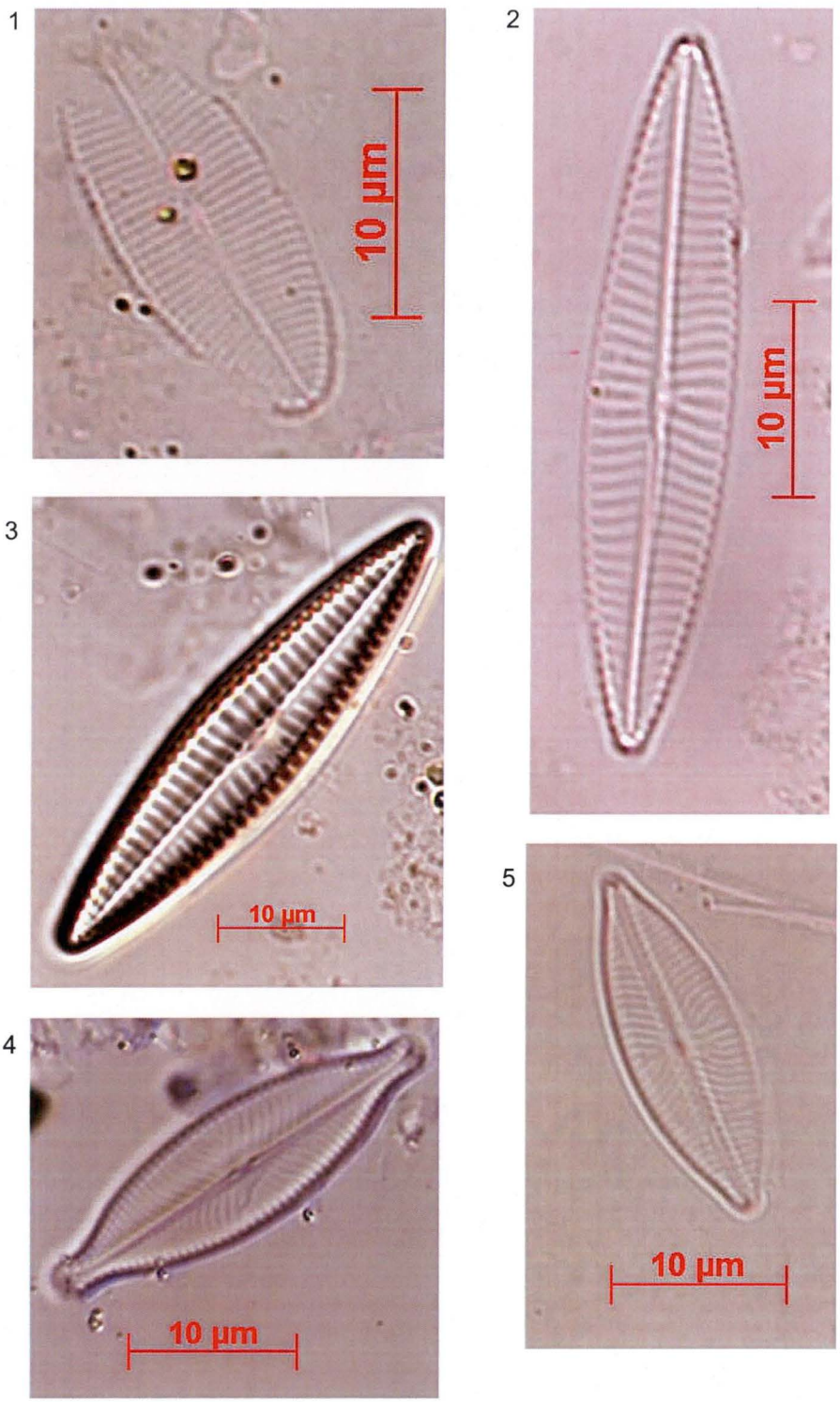
1. *Mastogloia* cf. *affirmata* (Leudiger-Fortmorel) Cleve
2. *Mastogloia parva* Hustedt
3-4. *Mastogloia pusilla* (Grunow) Cleve
5. *Microtabella interrupta* (Ehrenberg) F.E. Round

PLATE 25



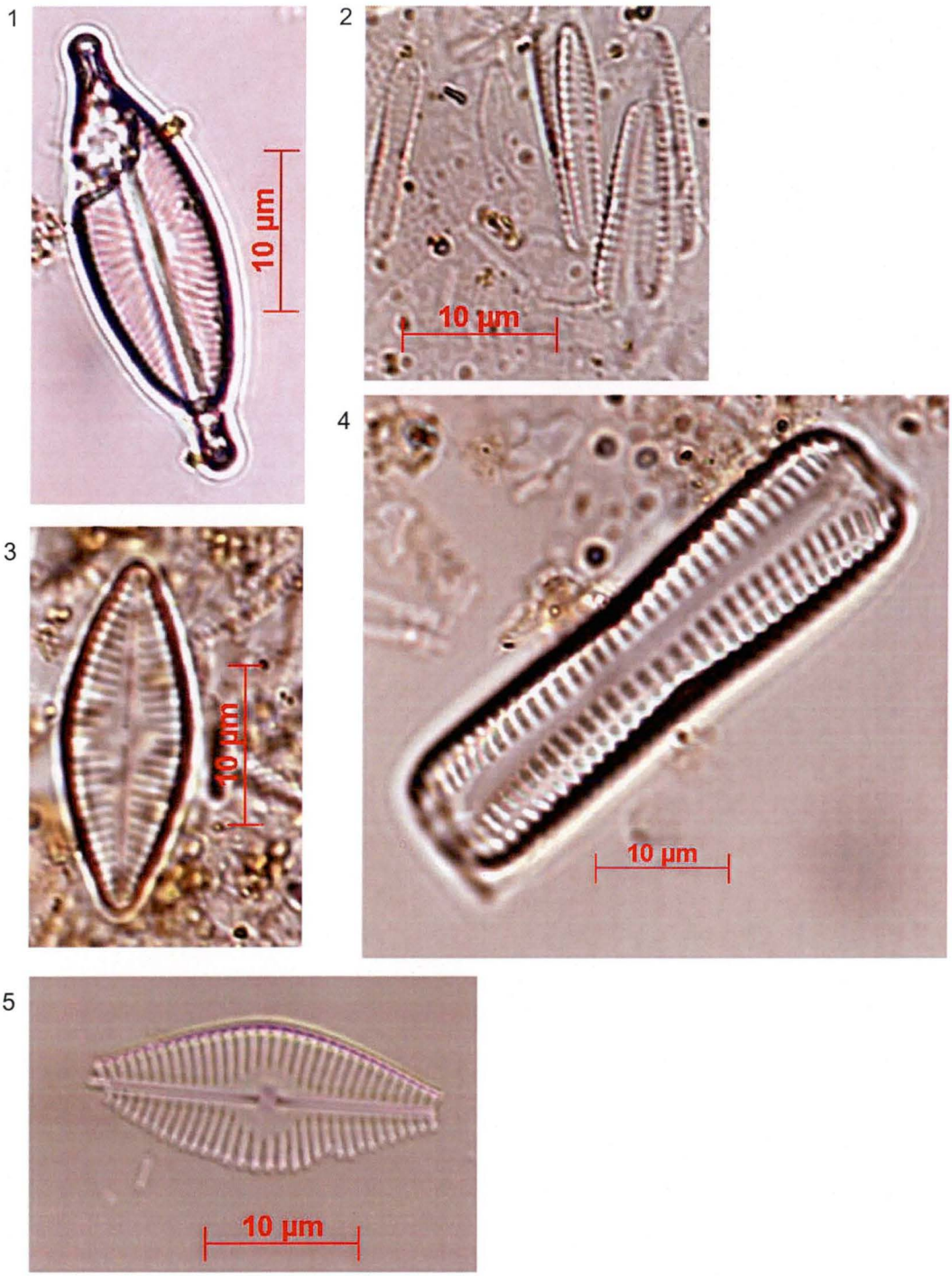
1. *Navicula digitoradiata* (Greogory) Ralfs
2. *Navicula* cf. *leptoloba* Meister
3. *Navicula* cf. *libonensis* Schoeman
4. *Navicula* cf. *lusoria* Giffen
5. *Navicula marina* Ralfs ex Pritchard
6. *Navicula perminuta* Grunow

PLATE 26



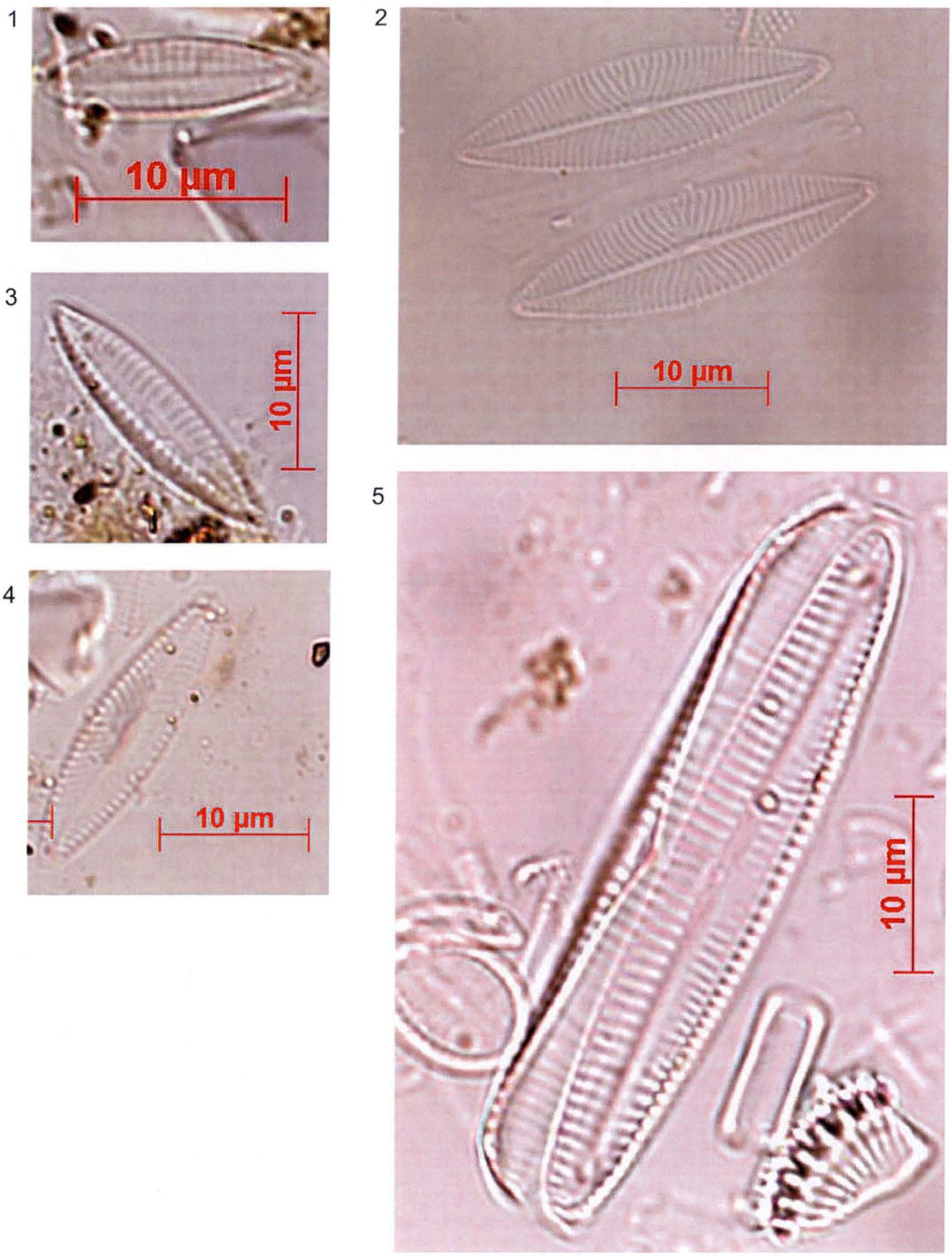
1. *Navicula* cf. *ramosissima* var. *torquata* (Harvey) R. Ross
2. *Navcula recens* Lange-Bertalot
3. *Navicula recens* var. 1
4. *Navicula salinarum* var. *salinarum* Grunow
5. *Navicula salinarum* var. 1

PLATE 27



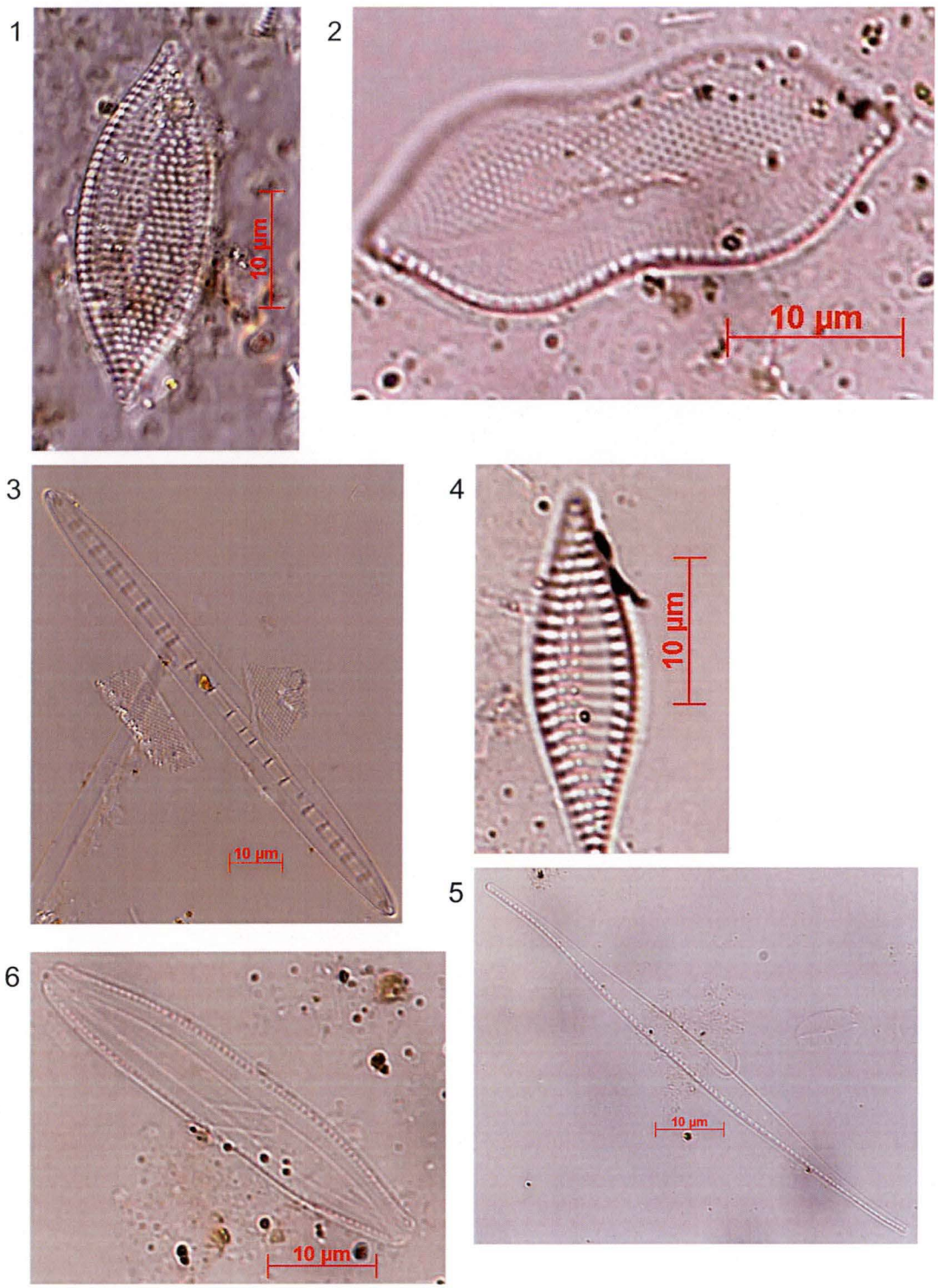
1. *Navicula* cf. *salinarum* var. 2
2. *Navicula* cf. *syvertsenii* Witkowski, Metzeltin & Lange-Bertalot
3. *Navicula yarrensis* Grunow
4. *Navicula* sp. 1
5. *Navicula* sp. 3

PLATE 28



1. *Navicula* sp. 4
2. *Navicula* sp. 5
3. *Navicula* sp. 6
4. *Navicula* sp. 7
5. *Navicula* sp. 8

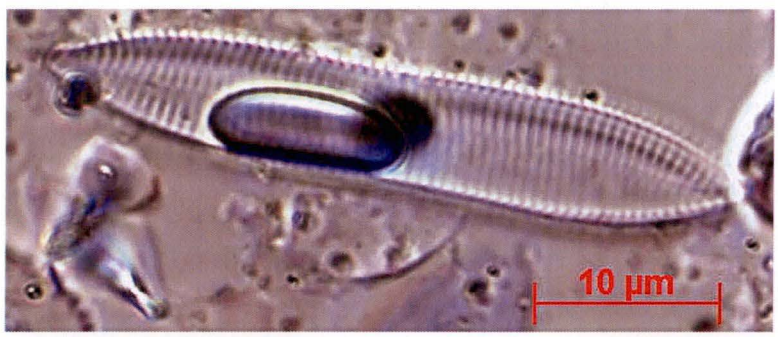
PLATE 29



1. *Nitzschia compressa* (Bailey) C.S. Boyer
2. *Nitzschia didyma* Hustedt
3. *Nitzschia* cf. *distans* W. Gregory
4. *Nitzschia lanceola* Grunow
5. *Nitzschia* cf. *lorenziana* Grunow
6. *Nitzschia* cf. *thermaloides* Hustedt

PLATE 30

1



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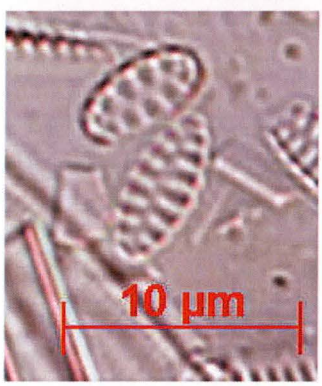

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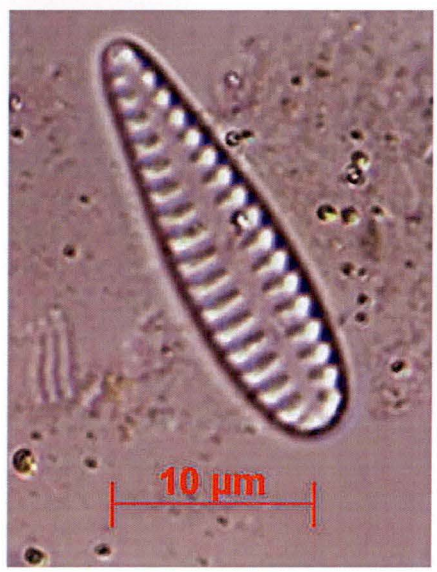

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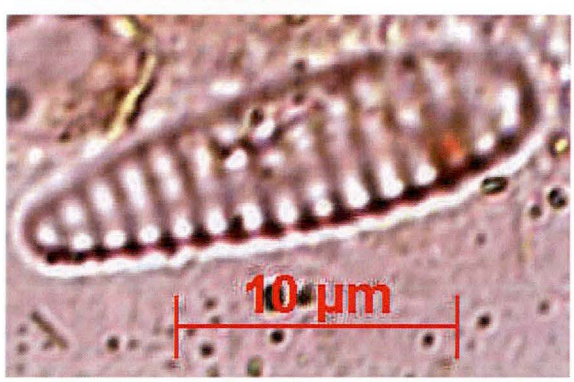
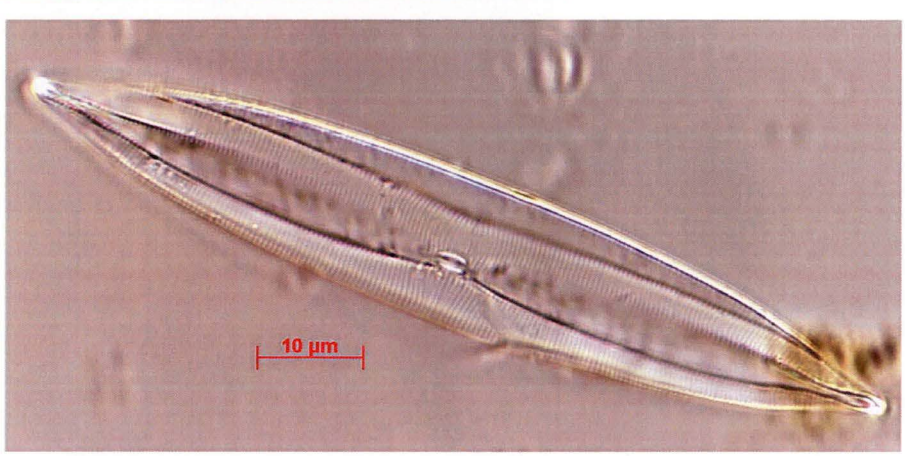


5



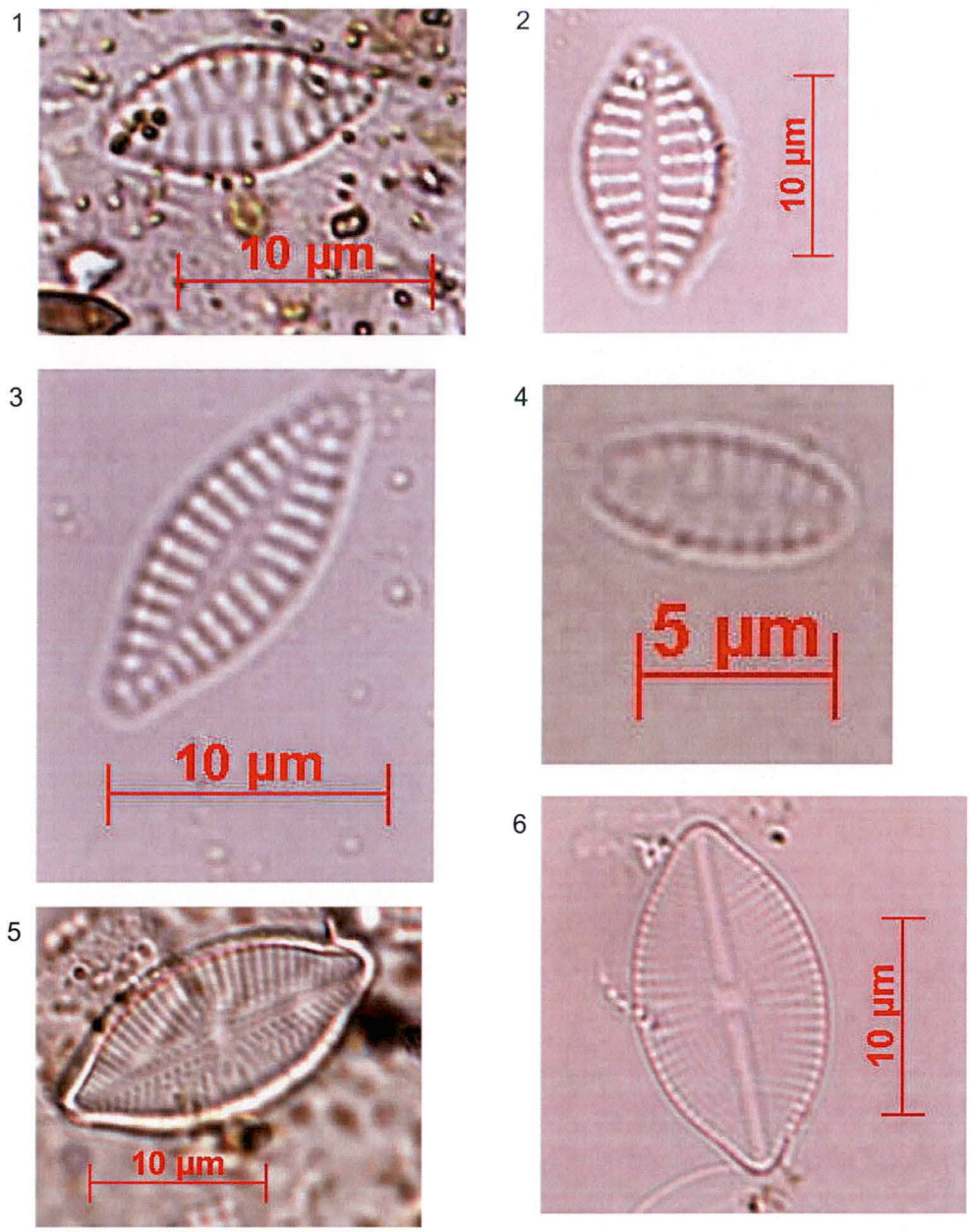
1. *Nitzschia* sp. 1

2. *Opephora guenter-grassii* (Witkowski & Lange-Bertalot) Sabbe & Vyverman

3-4. *Opephora pacifica* (Grunow) Petit

5. *Plagiotropsis* sp. 1

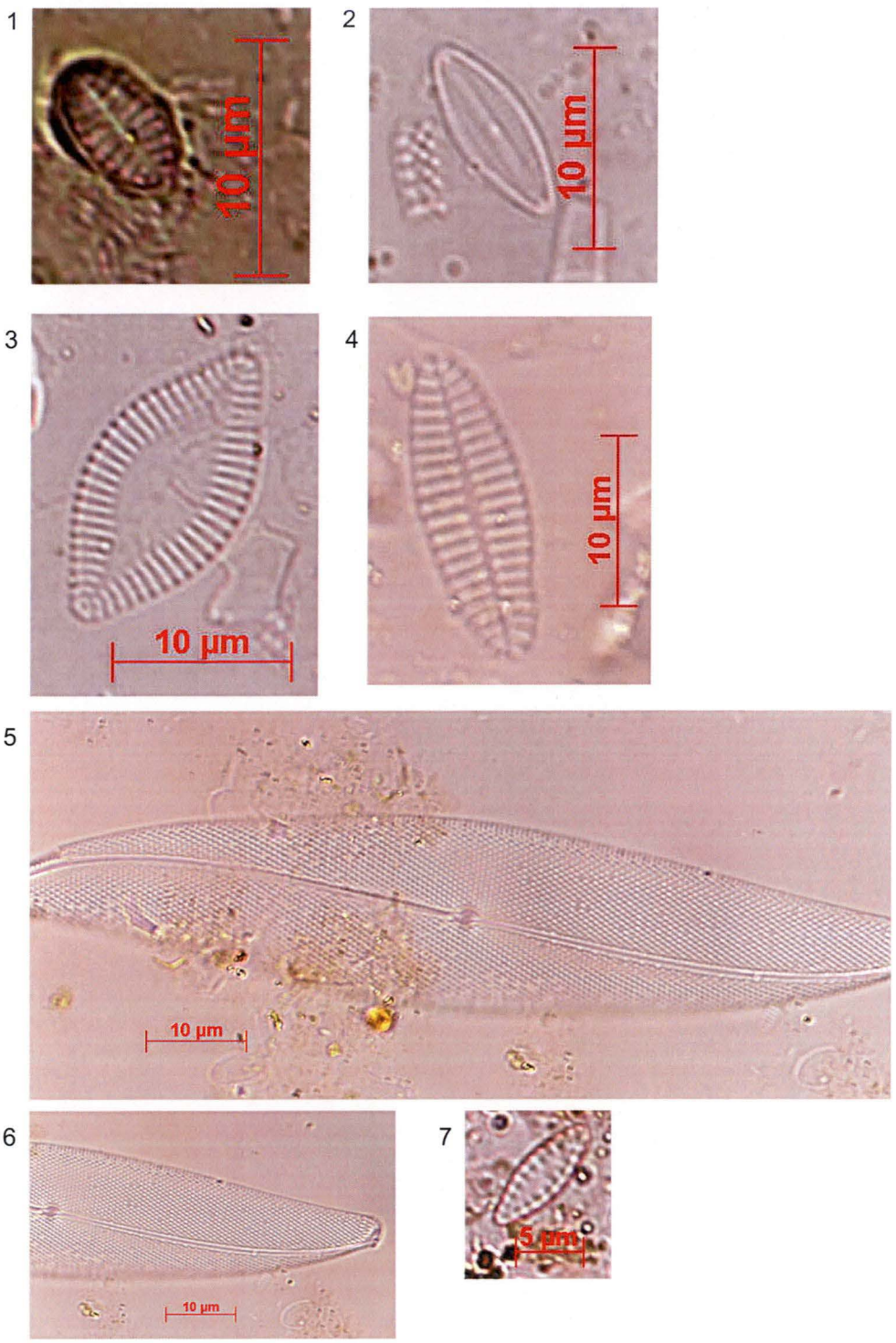
PLATE 31



1. *Planothidium delicatulum* (Kützing) Round and Bukhtiyarova
2. *Planothidium delicatulum* var. 1
3. *Planothidium delicatulum* var. 2
4. *Planothidium delicatulum* var. 3

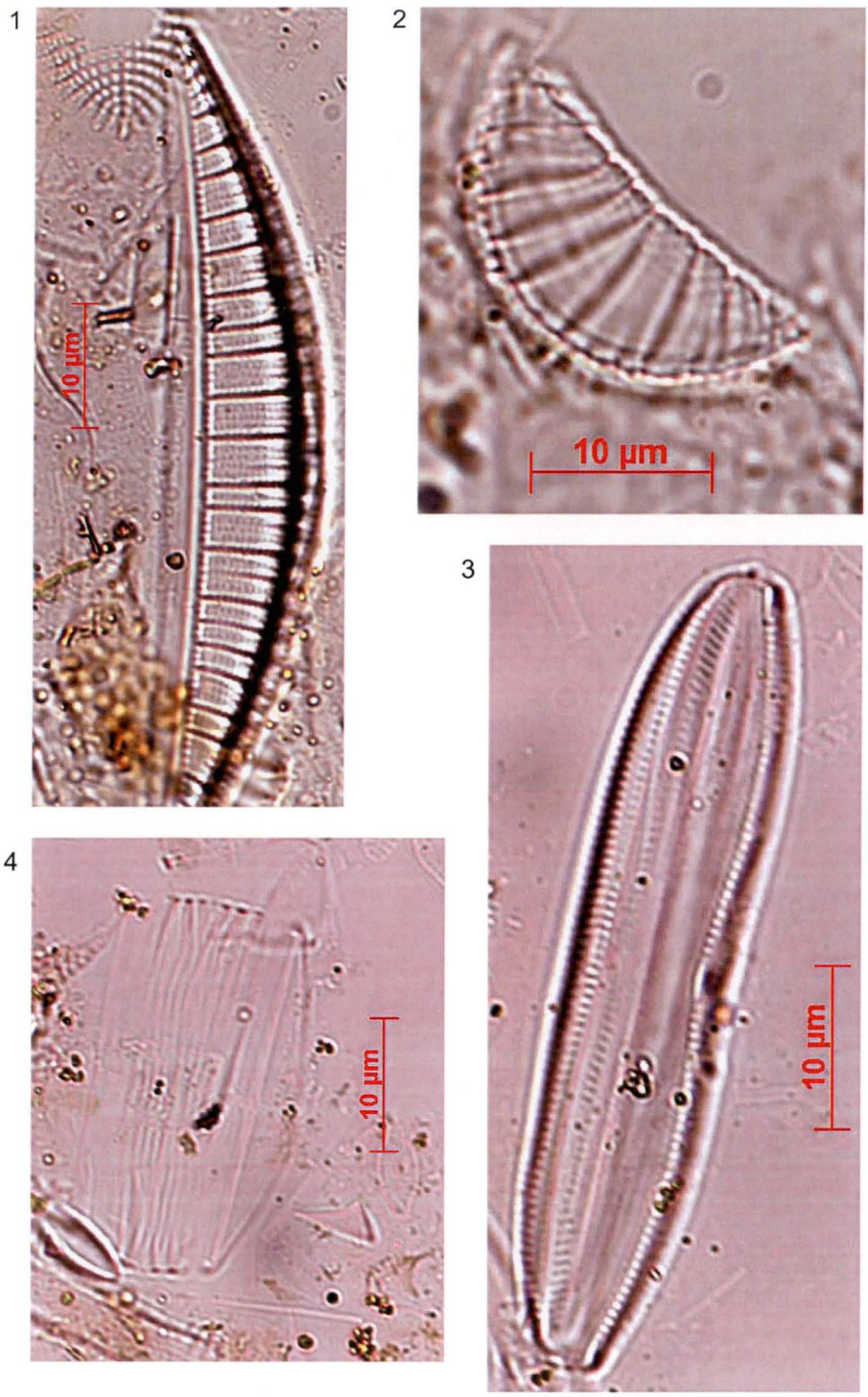
5-6. *Planothidium dispar* (Cleve) Witkowski

PLATE 32



1. *Planothidium hauckianum* (Grunow) Round & Buktiyarova
2. *Planothidium hauckianum* var. 1
3. *Planothidium quarnerensis* (Grunow) Witkowski
4. *Planothidium* cf. *polaris* (Østrup) Witkowski
5-6. *Pleurosigma* cf. *salinarum* (Grunow) Grunow
7. *Pseudostaurosira perminuta* (Grunow) Sabbe & Vyverman

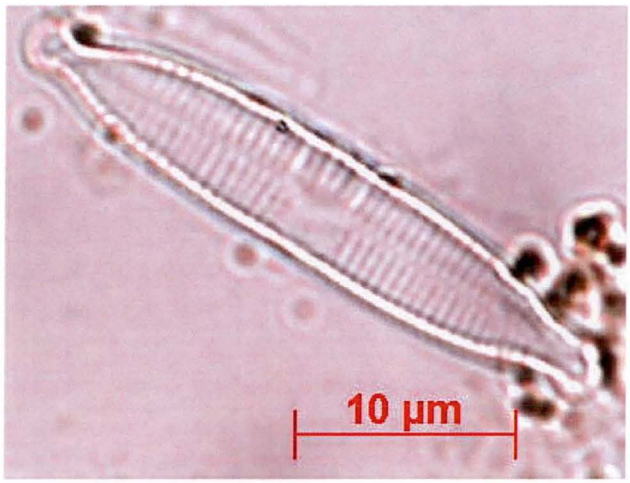
PLATE 33



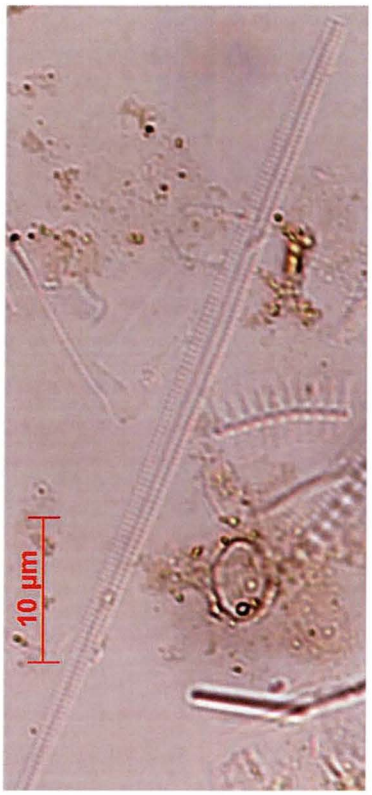
1. *Rhopalodia acuminata* Krammer
2. *Rhopalodia musculus* (Kützing) Müller
3. *Seminavis* sp. 1
4. *Stauroneis* sp. 1

PLATE 34

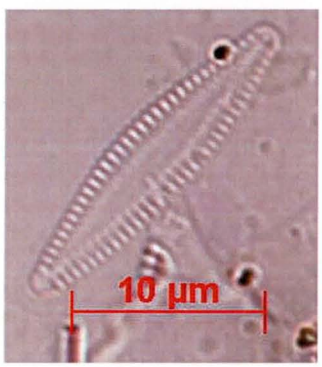
1



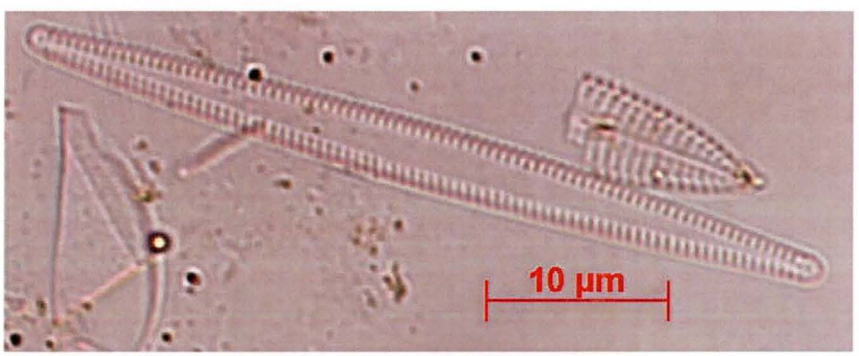
2



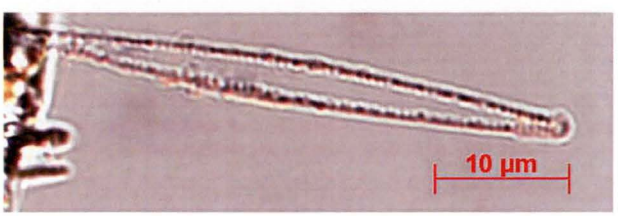
3



4

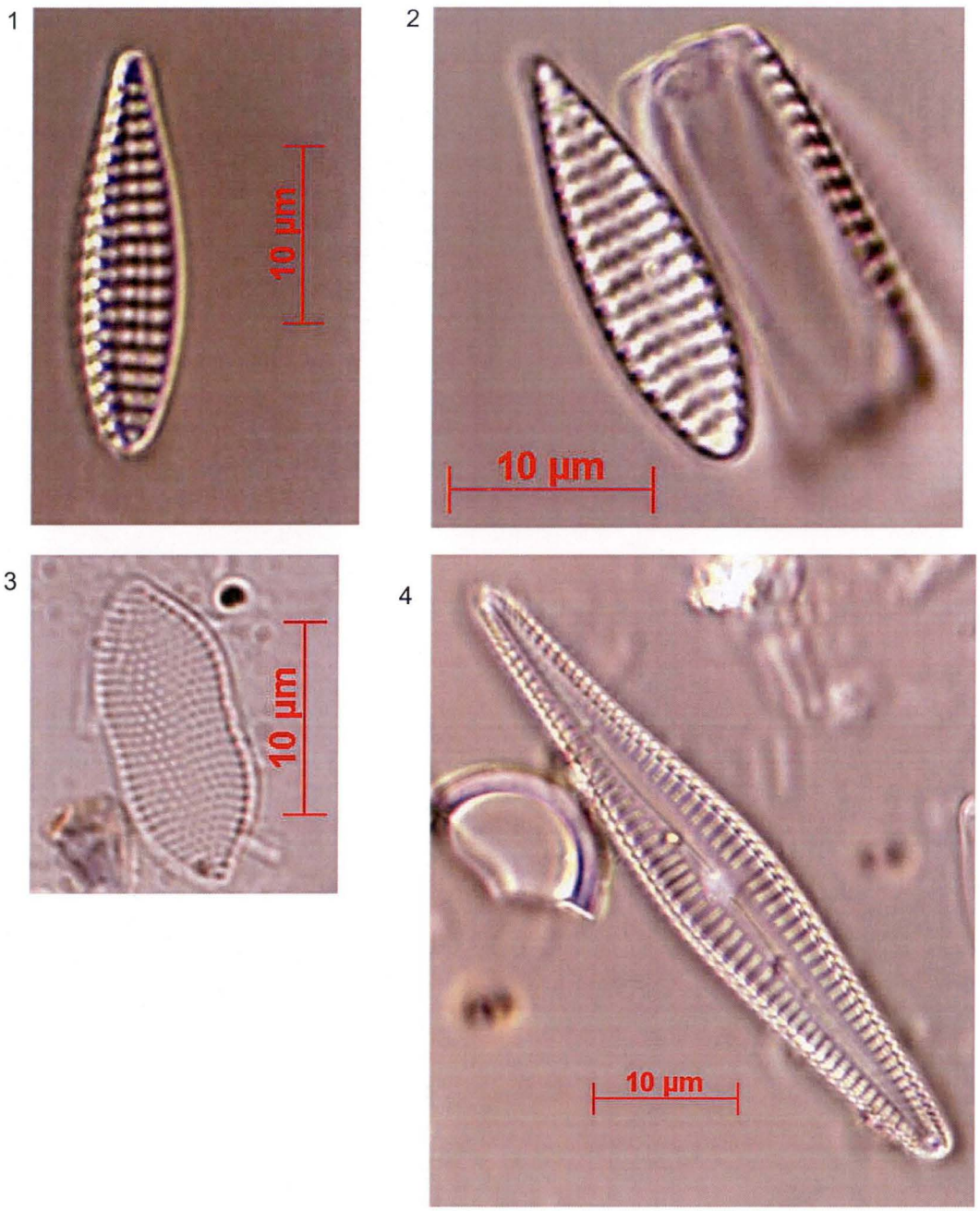


5



1. *Synedra* cf. *ulna* (Nitzsch) Ehrenberg
2. *Synedra* sp. 1
3. *Synedra* sp. 2
4. *Tabularia fasciculata* agg. (Agardh) Williams
5. *Tabularia* sp. 1

PLATE 35



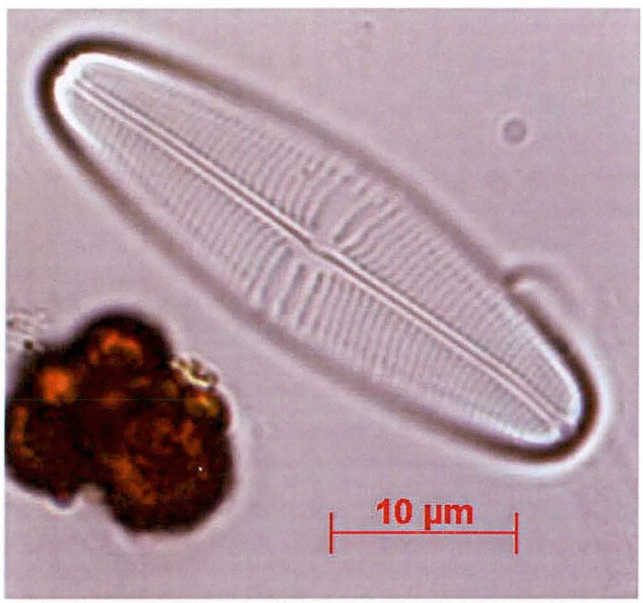
1-2. *Trachysphenia australis* var. *australis* Petit

3. *Tryblionella coarctata* (Grunow) D.G. Mann

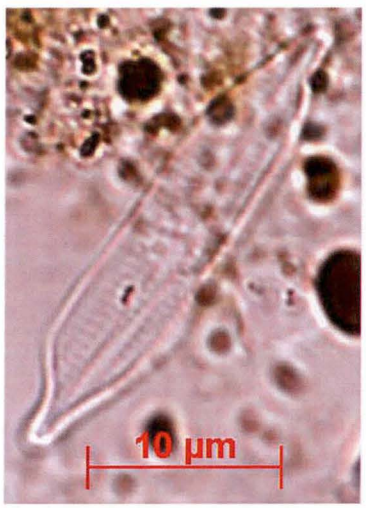
4. Unknown sp. 1

PLATE 36

1



2



3

1. Unknown sp. 3
2. Unknown sp. 4
3. Unknown sp. 6

Appendix 4: Tasmanian and Victorian diatom species optima and tolerances

Tasmanian species optima and tolerances. Note: count = number of occurrences, max = maximum relative abundance (%), N2 = effective number of occurrences, Opt = optima, Tol = tolerance, N = nitrate/nitrite, P = phosphate, Sal = salinity, Temp = temperature.

Code	Count	Max	N2	N Opt (µg N L-1)	N Tol (µg N L-1)	P Opt (µg P L-1)	P Tol (µg P L-1)	pH Opt	pH Tol	Sal Opt (ppt)	Sal Tol (ppt)	Temp Opt (°C)	Temp tol (°C)
ACH1	27	34 42	20.01	1 33	0.68	4.28	0 73	7 84	0.50	25.40	0 90	15 89	1.89
ACH14	3	5.61	2.71	1.72	0.42	5.07	1.10	7.77	0.41	31.57	0.06	14.88	2.35
ACH15	7	2 48	5.62	1.40	0 63	3.32	0.59	7.81	0.46	26.00	0.59	15.01	1.93
ACH17	1	1.75	1.00	1.59	0.55	7 03	0.92	7 73	0 42	33.00	0 65	13 95	1.71
ACH2	4	2.99	2 69	1.51	0.17	3.39	0.71	7.88	0.10	34.49	0.07	13.68	1 50
ACH22	2	1 25	1.99	1.48	0.17	4 59	0 75	7 81	0.13	32.56	0.02	13.90	0.07
ACH3	19	28.22	12.83	1.00	0.70	4 47	0 60	7.68	0.50	22.13	0.64	15.94	1.93
ACH6	2	1.75	1 69	1 95	0 36	5.71	0.20	8.00	0.27	21.74	0.49	16 80	2 83
ACH6a	13	5.26	9.64	1 52	0 68	6.14	0.63	7.71	0.40	23.42	0.54	14.86	1.86
ACHbre3	10	1.25	8.26	1.73	0.39	4.04	0.58	7.92	0.28	26.52	0.32	15.76	2.52
ACHpse	15	4 26	9 87	1 41	0.46	6.58	1.17	7.79	0 35	27 59	0.50	14 80	1 80
ACHres	23	4 50	14.13	1.20	0 77	6.33	1 17	7.92	0 45	25 23	0.73	14.57	1.53
ACHres5a	1	3 23	1 00	0.22	0.55	0.11	1 45	6.94	0 42	10 00	0.65	15 70	1 71
ACHres6	1	1 24	1.00	0 22	0 55	0.11	1.45	6.94	0.42	10.00	0.65	15.70	1 71
AMP1	34	39.53	26.42	1.35	0 63	5 22	0 77	7 89	0.38	24 56	0.78	15.53	2.02
AMP11	23	9 90	16.46	1 33	0.59	4.35	0.75	7.68	0 69	21.36	1.72	14.81	1.75
AMP14a	5	7 88	3 24	1 70	0 22	7 53	0 47	7.75	0 18	32 27	0 02	13 70	0.36
AMP15	5	3.86	2 72	0 66	0.94	10.68	1 27	8 45	0.61	30.08	0 06	15 37	2.05
AMP18	12	3 69	8 45	0.90	0.85	5.06	1.33	7 88	0.57	19.61	1.28	13 90	2.20
AMP3	12	3 48	7 91	0 95	0.73	4 73	0 74	7 75	0.55	19.88	0.96	14.21	2.43
AMP4	25	6.09	17 99	1 18	0.66	4.41	0 68	7 80	0.41	21.79	0.85	14.54	2.15
AMP6b	1	10.05	1 00	1 07	0.55	3.62	0.92	8 02	0.42	36.25	0.65	17.30	1 71
AMP9	19	9 57	13.49	1 34	0 74	3.62	0.65	7.88	0.33	28.56	0 43	15.13	1.83
AMPcof	32	7 97	25.29	1.36	0.71	4 78	0 75	7 91	0.40	23.73	0.69	15.08	2 20
AMPcof2	21	10.87	14 80	1.25	0.72	5 51	0.86	8.00	0 44	25 21	0.79	15.06	2 18
AMPlae	15	4 01	10.74	1 22	0 78	4 45	0 85	7 81	0.37	28.00	0 78	14 72	1 51
AMPlae2	5	4 88	3 80	1 89	0 38	6 53	0.60	7.77	0.32	27.51	0.36	15.06	2.69
AMPlae5	2	1.97	1 62	0.05	0.13	1.55	0.92	7.28	1.63	11.49	10.09	14.96	0.71
ARDfor	8	1.74	6 10	1 23	0.91	3 32	0.66	7.86	0 19	27.02	0.31	14.87	1.85
AULamb	1	7.82	1.00	0.19	0.55	0 08	1.45	5.57	0 42	0 00	0.65	15 70	1.71
BRF1	5	1.93	4 46	1 24	0.79	2.72	0 61	7.37	1 27	11 64	4.98	15.71	1.58
CEN1	20	4.24	12.84	1.43	0.54	6.41	1 57	7.81	0.42	25 93	0 54	15.11	2 21
CEN10	8	40.33	2.73	0.48	0 78	14 31	2 02	7.76	0 32	18 42	0.75	15.56	1 32

Code	Count	Max	N2	N Opt (µg N L-1)	N Tol (µg N L-1)	P Opt (µg P L-1)	P Tol (µg P L-1)	pH Opt	pH Tol	Sal Opt (ppt)	Sal Tol (ppt)	Temp Opt (°C)	Temp tol (°C)
CEN15	12	4.67	7.43	1.35	0.37	7.86	2 54	7.79	0 39	17 09	1.69	13 64	2 55
CEN5	8	11 50	4 85	1 66	0.39	4.00	0 57	8 10	0 22	25.85	0.28	17.43	2 05
CEN6a	1	18.85	1.00	0 27	0 55	0 11	1 45	4 94	0.42	1.00	0.65	15 70	1.71
CEN9	6	2 74	3 71	1 37	0.56	3.77	0 97	7.97	0.37	34.36	0.06	14.09	1 35
CEN9a	2	2 41	1.60	1.76	0 06	5 51	1 39	8 02	0 16	33 91	0 02	15 57	1.80
COC13	3	5.84	1.54	0.47	0.41	0 99	4.93	7.21	0.72	19.65	0.47	15 58	0.54
COC14	1	3 52	1.00	1.07	0.55	3.62	0.92	8.02	0.42	36.25	0.65	17 30	1 71
COC4	1	2.44	1.00	2.18	0.55	3 21	0 92	7 59	0.42	18.50	0.65	13.65	1 71
COC4a	1	1.45	1.00	0.00	0.55	13.07	0 92	8 87	0 42	30.05	0.65	15.25	1 71
COC8	3	7 04	1.82	0.83	0 67	11 20	0.37	8 19	0.55	21.42	0.42	15.70	0 37
COC9	10	1 72	7.33	1.22	0.58	3.25	0.48	7.77	0.40	29 84	0 33	14.82	1 37
COCcos	3	1 25	2.05	1.40	0.25	4.82	4.03	7.92	0.15	34.88	0.06	13.99	1 92
COCdis	26	8.27	18.71	1.49	0.48	5.75	1.17	7.89	0.33	25.92	0.47	15.92	2 32
COCpla	34	51.00	25.32	1.33	0 70	4.98	0.74	7.75	0.57	17 70	1 22	15.33	2.35
COCplae	11	3.72	7.68	1 84	0 71	4.75	0 67	7.95	0.20	21 57	0.39	15.75	2 17
COCscu	33	30.47	19.30	1.42	0.55	7.71	1 22	7.73	0.41	16.91	1.15	14.45	2 53
COCscup	7	2 25	5.46	1.77	0.37	4 27	0.64	7.91	0.36	26.23	0.26	16 16	2 56
CYCstr	10	6 09	6 37	0.91	0.79	5.00	1.09	7.66	0.48	15.21	1 62	14.13	3 26
CYCstr3	28	29 01	15.43	1 13	0.71	6.37	1.32	7.60	0.79	17 92	1.47	14 78	1.96
CYMasp3	4	4 18	3 08	1 49	0.52	3.97	0.14	7.78	0.19	27.35	0.41	14 65	1 63
DELmin	8	4 73	5 54	1.28	0 63	5.16	0.67	7.49	0 45	16.74	0.74	14 38	2.37
DIP10	1	1 49	1 00	1 24	0.55	2.59	0.89	8 11	0 42	35 60	0.65	15.45	1.71
DIP5	6	5 17	4 29	1 39	0.53	3.50	0 83	7 97	0 10	32 73	0.29	14.60	1 31
DIP7	26	13 90	18 80	1 39	0 58	2 88	0 39	7 83	0 40	25.20	0.43	15.89	1 85
DIPnot	14	4.67	7.63	1.24	0 66	4 94	1 17	7.71	0.41	14.19	1.74	13 32	2 51
EPI1	3	10.87	1.52	0 31	1.04	10.86	0.91	8 65	0 74	30.56	0.06	14.98	0.92
EPI1a	3	7 00	1 44	0 20	0 80	11 37	1 00	8 73	0 54	30.77	0.09	15 21	0.52
FAL10	3	10.98	2 14	2 12	0.17	8.66	0.34	7 70	0 45	26.08	0.50	15.30	2.68
FAL11	2	2 00	1 64	1 59	0 18	2 49	0.21	7 95	0.12	35.34	0.03	13.84	2.26
FAL12	1	2 48	1 00	1 24	0.55	2.59	0.89	8 11	0 42	35 60	0 65	15.45	1.71
FAL2	9	3.90	5 09	1 64	0 42	7 37	0 79	7 68	0.34	22.62	1.43	13 78	2.05
FAL4	1	2 00	1 00	1 52	0.55	2.03	0.92	7 91	0 42	35.80	0.65	13.00	1 71
FAL5	16	7.54	11.69	1.21	0 72	3 95	0 71	7 83	0.18	28.94	0 26	14.95	1.52
FRA1	5	2 75	3.58	1 64	0.38	4.08	0.55	8.16	0.16	25.66	0.26	18.04	1 35
FRA3	4	5 29	2 88	0 69	0 88	4 22	0 45	6 67	1.40	4.12	6.50	15 98	0.72
FRA5	2	5 75	1.51	0.25	0.05	0.10	0.02	5.08	0.45	0 72	0 63	15.70	1 71
FRA7	1	1 51	1.00	1 07	0.55	3.62	0.92	8 02	0.42	36.25	0.65	17 30	1.71

Code	Count	Max	N2	N Opt (µg N L-1)	N Tol (µg N L-1)	P Opt (µg P L-1)	P Tol (µg P L-1)	pH Opt	pH Tol	Sal Opt (ppt)	Sal Tol (ppt)	Temp Opt (°C)	Temp tol (°C)
FRAgeo	8	1.72	6.15	1.25	0 90	3 66	0 97	7 75	0 79	23 07	2 06	15 56	1 57
FRAque	7	2 99	4.97	1.57	0 29	4.96	0.48	7 92	0.20	30.72	0 17	14 32	2.28
FRAvir	3	1 98	1.78	1.18	0 42	5 20	0 23	7 83	0 23	33.81	0 03	15.54	1.68
GRA2	2	1 25	1.93	2.10	0 55	5 40	0.05	8 15	0.08	19.10	0 07	18 13	0.32
GRA3	3	1 41	2 47	1.42	0.54	3 67	0.68	8 01	0.14	31.81	0.42	14.65	1 88
GRAmac	10	2.82	6 48	1.22	0.59	9.78	1.93	7.95	0.21	29.75	0.35	15.51	1.44
GRAmar	5	3.75	3.60	1.63	0.68	12 91	3.16	7.86	0.37	22 37	0.41	16.62	1 51
GRAoce	18	41.87	9 13	1 32	0.64	10.21	2.23	7.83	0.45	21.24	1 18	15.20	1.80
GRAsub	4	5 98	2 56	1 52	0 60	27 56	2.70	7.77	0 25	29 44	0.37	15.67	1 21
GYRatt1	1	1 23	1.00	1.35	0 55	4 12	0.92	7.94	0 42	34.65	0.65	14.15	1 71
GYRbal	22	2 49	15 77	1 29	0.60	4.94	0.91	7.85	0.53	27 31	0.78	15.09	2 04
MAS2	6	1.91	4 88	1 03	0 33	14 10	3 28	7 66	0.44	23.66	0.87	15 60	1 86
MAS2a	9	24 88	4 04	0 94	0.64	2.90	0.51	7.91	0.23	31 66	0 20	14.62	0.65
MAS3	4	2 15	2 33	1 01	0 57	24 66	4 65	7.88	0.22	31.93	0.07	15.78	0 65
NAV1	17	3.00	15.30	1 24	0 64	4.67	1.03	7.63	0 60	21 52	1.46	14 69	1 49
NAV10	15	3 41	11 71	1 19	0 69	4.10	0.68	7.80	0.41	24 90	0.46	15 35	2.05
NAV2	5	1 99	3 06	1 60	0 40	3.82	0 52	7 89	0 05	29 65	0.33	13 91	1.35
NAV24	1	7 14	1.00	1.24	0.55	2 59	0.89	7.98	0.42	34.80	0.65	14 35	1 71
NAV3	29	11 47	20.76	1 34	0 74	5 98	1 11	7.79	0.68	23.07	1.50	15 27	1 90
NAV32a	2	1 24	1 97	0 82	1 02	2 59	0 17	7.35	0 40	13 57	1.35	12.68	2 72
NAV4	23	6 77	15.71	1 28	0 71	5 81	0 83	7.73	0 77	21 63	1.82	14 70	1 49
NAV42	4	5 28	3 22	0 90	0 33	11 01	0 29	7.78	0 60	22 63	0.43	15.72	0 16
NAV43	2	1 20	1 50	1.63	0 50	3 99	0 14	8 09	0 04	34.22	0.01	16 08	0 39
NAV44	1	4 89	1.00	2 18	0.55	3 21	0.92	7.59	0.42	18 50	0.65	13.65	1.71
NAV7	28	5 75	20 72	1 37	0.67	4.18	0.78	7.89	0 32	26.53	0.56	15.21	1 99
NAV7b	1	6.51	1.00	1.07	0.55	7 12	0.92	8.19	0.42	35 30	0.65	18.20	1.71
NAVper	32	14.29	22 94	1 40	0.68	4.50	0.75	7.82	0 42	24 94	0.70	15.28	2.03
NAVryn3	6	1 43	4 35	1 57	0.30	4 75	0.59	8.08	0 19	28.12	0.22	16.63	2.44
NAVvir	2	1.42	1 58	0 00	0 55	15 38	4 69	7 79	0.08	16.90	0.62	15.38	0 64
NAVvir3	1	2.70	1.00	1.35	0 55	4 12	0 92	7 94	0.42	34.65	0.65	14 15	1 71
NIT10	2	2 25	1 88	1 52	0 33	6.68	3.24	7.93	0.15	34.14	0 04	14 38	1.38
NIT6	16	9 20	9 42	0 98	0 70	4 75	1 08	7 40	1.04	14.02	3.52	15.52	1 46
NIT6a	5	3.75	3.34	1.65	0 42	3 90	0.64	8 15	0.18	25.49	0 31	17.90	1 42
NITpan1	3	1 50	1.98	1 49	0 13	2 78	0 42	8 16	0.23	29.14	0 06	17 37	3 10
NITscal	22	3 48	14 85	1 43	0.50	4.78	1.02	7.86	0.27	26.58	0.58	14.83	2.00
NITval	23	14.85	14 71	1 14	0 64	4 15	0 87	7 90	0.37	26.88	0.49	15.56	2.00
OPE3	28	17.12	16.31	1 52	0 60	5.77	0.74	7 80	0.63	19.71	1.46	15.82	2.40

Code	Count	Max	N2	N Opt (µg N L-1)	N Tol (µg N L-1)	P Opt (µg P L-1)	P Tol (µg P L-1)	pH Opt	pH Tol	Sal Opt (ppt)	Sal Tol (ppt)	Temp Opt (°C)	Temp tol (°C)
OPEbur	36	64.22	27.56	1.42	0.71	5.66	0.94	7 94	0.34	26.07	0 58	15.58	1 89
OPEbur2	1	20.29	1.00	1.59	0 55	6 01	0.92	7.85	0.42	31.75	0.65	13.70	1 71
OPEgue	33	15 33	27 05	1.27	0.78	5 12	0 86	7 88	0.58	23.26	1.12	15.56	1 74
OPEmar	21	6 48	14 77	1 71	0.47	4.95	0.52	7 96	0.28	26.09	0 44	15.99	2.31
PARsul	14	4.94	11.66	1.24	0.72	4.80	0 94	7.83	0 15	30 87	0.22	14 56	1.40
PIN4	3	1 15	2 11	0.40	0.44	1.13	5.61	5.66	1.72	2.03	4.24	15.69	0 03
PLAdel	36	28.75	25 56	1.31	0.66	5 72	0.89	7.86	0.40	23 48	0 72	15.21	1 92
PLAdel3	6	3.48	4.31	1.52	0.22	4 00	0 42	7.85	0 14	32.19	0.06	13.73	1.46
PLAdel4	3	1.25	2 36	1.65	0.07	4 70	0.35	7.81	0.05	31 74	0.02	13 03	0 88
PLAhau	33	25.69	25 44	1.35	0 59	4 63	0 78	7.73	0.66	21.63	1 49	15 28	1 93
PLAhau3	14	21 97	8.70	1.37	0 64	4.54	0.36	7 72	0 44	26.18	0 57	14.99	1 65
PLAhau3a	1	24.19	1 00	1.94	0.55	3 75	0 89	7.29	0.42	6 05	0 65	12.45	1 71
PLAhau3b	1	11 52	1.00	1.94	0 55	3 75	0 89	7.29	0.42	6 05	0 65	12.45	1 71
PLAhau4	1	1 15	1.00	0.19	0.55	0 08	1 45	5 57	0.42	0 00	0.65	15.70	1 71
PLAlan	13	1.70	10.64	1.27	0.76	6 06	0.83	7.66	0.45	19 81	0.62	14 94	2 01
PLApol3	2	1.23	1.51	1.53	0.59	3.91	0 15	7 86	0.25	30.32	0.53	14.04	0 35
PSEper	2	1.44	2.00	1 24	0 55	12 00	10 63	7 91	0.21	33.52	0 08	15.86	0.35
RHA2	5	3.69	3.10	1 29	0 57	14 47	1 49	7 45	0.40	9 72	2.52	12.84	2.96
RHA3	22	34.15	10 94	1.17	0.69	7 99	1.55	7.71	0.42	14.13	1.74	13.60	2.40
RHOacu	23	34 15	12 26	1.16	0.71	8.12	1.58	7 64	0.46	14 88	1 48	13.63	2 36
RHOacu2	2	1 49	1 46	0 39	0 60	4 43	0.48	7 07	0.48	11.34	0 52	16.17	1 70
STA2	2	2 71	1.69	1.42	0 46	3 39	0 65	7.95	0.06	34.80	0 65	14.35	1 71
SYN1	3	3 00	1 65	2 00	0 38	5 26	0.55	8 01	0.34	21.06	0.45	16.96	2.79
SYNcam	9	1.50	6.75	1.64	0 74	9 22	1.00	7.70	1 08	20.77	1 59	16.83	2 02
SYNfas	20	4.75	13.40	1 37	0 76	6 31	0 74	7 83	0.51	19.88	0 72	15.37	2 31
UNK100c	4	2.49	2.70	1.76	0.36	3 52	0 55	7.92	0.32	13.79	1.57	13 93	3.97
UNK102	7	2 24	5.71	1.28	0 61	3 55	0 95	7 96	0.19	32.43	0.12	15 00	2.15
UNK102a	1	1 20	1.00	1.78	0.55	3 79	0 92	8.08	0 42	34.10	0.65	16 20	1.71
UNK107	10	9.25	7.95	1.30	0 38	4.23	0 86	7 89	0.33	31.73	0 22	14.56	1 40
UNK117c	3	14 02	2.36	0.22	0 05	0.09	0.02	5 50	0 77	0.67	1 64	15.70	1 71
UNK126	1	9 07	1.00	1.59	0 55	6.01	0 92	7 85	0 42	31.75	0 65	13 70	1 71
UNK19b	9	3 95	6.91	1.56	0 47	4 03	0.36	7 85	0.19	28.02	0 34	14.84	1 90
UNK19c	4	1.64	3 21	0.54	0.62	4 96	1 73	7 91	0.42	25.38	0 53	15 29	0.61
UNK19d	2	2 49	1 85	1 57	0 24	4.96	1.73	7 85	0.07	31 63	0.01	12.95	0 99
UNK200	1	1.74	1 00	0.00	0.55	2.17	0 92	7.67	0.42	27.80	0 65	14.85	1 71
UNK206	3	16 32	1 88	0 23	0 10	0 23	0.84	5 30	1.09	1 02	2.16	15.63	0.37
UNK207	2	2.76	1.53	0 25	0 05	0 10	0.02	5.08	0.45	0.71	0 63	15.70	1.71

Code	Count	Max	N2	N Opt (µg N L-1)	N Tol (µg N L-1)	P Opt (µg P L-1)	P Tol (µg P L-1)	pH Opt	pH Tol	Sal Opt (ppt)	Sal Tol (ppt)	Temp Opt (°C)	Temp tol (°C)
UNK24	8	1.25	6 82	1 77	0.49	4.53	0.97	7.93	0 25	32 59	0.14	14 92	2.12
UNK27	6	2 50	3.74	1 83	0.61	5.56	0.54	8.04	0.31	23.51	0.37	15.63	2 99
UNK27a	3	4 12	2 60	1 93	0.35	4.54	0.39	7.78	0.20	26.98	0 46	14.04	0.42
UNK28	1	1 18	1 00	1.07	0.55	4.80	0.92	8.13	0.42	34.65	0.65	15.65	1 71
UNK30	24	3.24	19.21	1 39	0.66	4.44	0.69	7.64	0.90	19.09	1.81	15 01	1.97
UNK37b	7	51.38	5.20	1.40	0 79	4 72	0 95	7.41	0.38	8.14	0.70	12 86	2.38
UNK43	8	44.37	2 64	0 67	0 74	23.65	3.42	6.14	1 80	5.40	4.59	15.47	1 10
UNK5	32	21 36	23.48	1.25	0.67	4.75	0.76	7 79	0.42	24.35	0.60	15 55	1.96
UNK69	4	1 25	3 28	1 62	0.41	4.94	0.54	7.86	0 17	32 65	0 05	14.00	1.60
UNK7	12	2.35	9 65	1 53	0 38	4.41	0 55	7 95	0 14	28.95	0 43	14.94	1 87
UNK80	5	5.31	3 56	0 47	0 94	5 89	1 19	8 20	0 63	30 54	0 11	15.16	0.99
UNK88	4	2.90	2 82	0.85	1.13	7.31	1.03	8.46	0.53	27 06	0 32	15 66	1.79
VIK7	1	2.72	1.00	1.07	0 55	4.71	0 92	7 75	0 42	33.35	0 65	15.25	1.71
VIK8a	4	12.20	2.60	1.72	0 58	7.05	0 55	7 75	0 40	31.60	0 22	14 64	1.77
VIKpro	4	1.00	3.46	1 68	0.35	4.36	0.50	7.75	0.13	28.51	0.31	13.66	0.57

Victorian species optima and tolerances. Note: count = number of occurrences, Max = maximum relative abundance (%), N2 = effective number of occurrences, Opt = optima, Tol = tolerance, N = nitrate/nitrite, P = phosphate, Sal = salinity, Turb = turbidity.

Code	Count	Max	N2	N Opt (µg N L-1)	N Tol (µg N L-1)	P Opt (µg P L-1)	P Tol (µg P L-1)	Sal Opt (ppt)	Sal Tol (ppt)	Turb Opt (NTU)	Turb Tol (NTU)
ACH1	41	1 75	33 95	23.23	10 46	17.18	2.92	26.88	0.34	5.17	1.69
ACH11	4	0 45	2.78	6.83	3.44	7.17	1.67	25.95	0.71	3.83	0.76
ACH14	13	1 35	8 98	101.44	12 50	66.51	2.32	33.32	0.15	3.99	3.05
ACH15	14	0 79	8.72	84.98	18 26	23.17	3.06	25.10	0 51	12.52	1 44
ACH2	14	0.35	10.80	45 06	8 54	49.61	3.29	25.35	1 12	5 79	2 41
ACH3	20	0.71	16.47	6.69	6 70	9.10	2.06	24.84	0 32	3 90	1 94
ACH5	5	0.59	3.27	71.37	7 66	98.43	1.60	33.74	0 05	3 18	1.45
ACH6	9	0.65	5.54	6 49	9 48	9.34	1.01	20.62	0 27	5 90	1 75
ACH6a	13	0.90	9.60	5 91	10.36	9 32	1 34	23.32	0.27	4.52	1.68
ACHbre3	21	0.59	16.86	20 69	7.49	16 87	3.22	23.55	1.21	8.64	2.35
ACHpse	26	0.76	16.35	75.86	16.79	22 16	2.82	25.99	0.68	7.81	2.53
ACHres	26	0.92	17.01	8.55	8.59	12 54	2 36	27.61	0.31	3.58	1.73
ACHres3	3	0.34	2.51	8 44	1.70	4 97	1 38	35.86	0.01	3.93	1.48
AMP1	43	1.61	33.43	28.44	14 03	17.95	3.19	26.26	0.38	6.58	2.36
AMP11	27	0.68	19 39	41 72	9.49	20 00	3 15	28 91	0.43	9.82	3.01
AMP14a	6	0.74	4.69	53 19	29 90	33.35	8 83	31.95	0.18	9.24	2.90
AMP15	19	0.48	14 25	9.24	4.48	6.21	1 59	25.56	0.31	5 22	2.09
AMP3	10	1.21	7 20	228 79	27 08	57.97	4.92	31.84	0.13	11.06	2.65
AMP4	31	0 71	22.73	30.92	11 80	11.30	2.56	28.80	0.25	6.68	2.15
AMP7	2	0 33	1 82	11 40	0.25	12 95	0 16	25.10	0 44	1 49	1 82
AMP9	31	0.85	21 65	29.99	11.46	16.62	3.65	28.12	0 33	5 19	2.05
AMP9a	6	0 38	4 16	17.14	5.17	24.06	6 04	32.25	0.28	7.21	0.74
AMPcof	34	0.83	23 94	17 34	8.59	10 41	3.01	26.20	0.44	6.83	1.96
AMPcof2	29	0 64	20 49	54.28	9.80	18 64	2 21	27 81	0 59	7 95	2 41
AMPcof3	12	0 38	9 92	12 27	2.42	9 75	1 38	29 58	0.28	7 40	3 03
AMPlae	29	0.82	19.50	44.19	17.24	28.76	4.01	27 36	0.34	7.00	2.20
AMPlae1	3	0 87	1.65	20 51	4 73	32 35	5.66	32.19	0.32	1.95	0.45
AMPlae1a	1	0.33	1 00	0.75	6.89	25 52	2.38	20 85	0.40	4.00	1 84
AMPlae2	11	0 86	9 20	99 83	12.34	26 79	2.36	28 73	0.42	8.86	2.16
ARDfor	11	0 67	7 81	7.14	4.76	5 30	2 04	29 79	0 20	8.05	1.37
BER1	3	0 69	1 56	38.23	0 90	15.75	0.83	29.40	0.67	18.29	1.46
BRF1	5	0 35	4 29	1252.02	7.62	107 22	1.05	33 71	0 03	9.73	4.41

Code	Count	Max	N2	N Opt (µg N L-1)	N Tol (µg N L-1)	P Opt (µg P L-1)	P Tol (µg P L-1)	Sal Opt (ppt)	Sal Tol (ppt)	Turb Opt (NTU)	Turb Tol (NTU)
CEN1	29	1 74	13 73	33 33	6.87	7.53	1 64	27 98	0.69	15.32	2 80
CEN15	8	0 90	3.08	226.46	52.05	46 51	2.93	3 71	4 23	36.50	4 98
CEN2	6	0.30	4.60	7 16	2 08	11 01	3.90	27.41	0.27	3.58	0 72
CEN5	27	1.19	16 06	22.25	6.08	9.82	2 31	26 60	0.53	9 79	1.74
CEN7	3	0.40	2.36	44 67	3 09	9 41	0.59	13.89	0 71	4.93	1 82
CEN9	3	0 54	2 39	153.54	8 73	57 03	0.04	36.34	0 15	29 53	8 15
COC8	2	0.64	1.99	123.82	14 24	57 62	0.04	33 57	0 00	1.48	0 33
COCcos	8	0.57	5.24	244 31	14 33	116.89	2 00	34 00	0.09	10 32	2.53
COCdis	32	1.76	19.19	35 58	10 25	35 94	4.75	30.74	0 28	7.68	1 56
COChet	13	0 44	9 81	9.66	7 97	7.00	1 67	24.71	0 44	6 48	0.87
COCmol	7	0.76	4.41	38 67	3.30	106 03	4 84	34.05	0 07	8 23	1.01
COCpel	5	0 72	3 26	8.15	1 56	31.90	6.25	31.16	0.25	5.36	0 57
COCpla	25	0 93	14.82	34 49	7.39	12.70	2 65	26.78	0.51	7.99	1.68
COCpla1	3	0.54	1.98	32.83	2 69	76 43	0.56	35.42	0 04	3.11	0.90
COCplae	14	0 65	8 97	27 89	12 18	17.62	6 71	23.78	0 54	9.14	1.56
COCscu	34	0 81	24 93	24 07	7 33	18.18	4 15	26.79	0 58	7.76	1.53
COCscup	18	1.00	9.64	20.25	8 20	20 14	7.15	28.54	0 31	8.12	1 13
COCvet	10	0.89	5 89	11.13	3 88	5.22	2.04	24 60	0.48	9.19	0.94
CYC2	16	1 11	8 71	28 55	12 63	8.49	2.33	18.98	1.10	10.29	2.14
CYCstr	19	1 14	13.20	13.40	7.47	6.51	1 70	21.81	0 45	6.63	1.50
CYCstr2	5	0.67	3 49	9 17	1 57	4 00	0 82	28.24	0 43	4.22	1.64
CYCstr3	12	0 92	7 02	22.84	7.99	14.15	1.36	14.55	1 32	7.80	1.75
CYMasp	6	0 57	3.62	8 58	5.73	3.54	0 94	21.07	0.40	4 60	1.48
DELmin	12	0.70	7.32	55 36	18.48	13.12	3 85	21.33	0.63	10 49	1.50
DIP7	21	0 87	15.33	19.77	13.36	29 77	2.84	29 48	0.22	3.91	1 98
DIP9	1	0.42	1.00	0 75	6 89	25 52	2.38	20 85	0.40	4 00	1.84
DIPnot2	3	0.34	2 77	19 98	0 65	56 78	0 13	34 51	0.03	0 95	0.65
EPIzeb	3	1 03	1.39	25 18	4 81	10 86	9.51	38 30	0.24	70.36	13.59
FAL10	5	0 61	3 66	326 58	17.55	78 57	0 91	32.98	0 04	5 27	3 22
FAL2	8	0.35	6.56	103 71	22.01	58 78	5.27	31.44	0.20	8 68	2.22
FAL5	32	0 65	22 48	13.72	12.95	12.77	2.68	25.92	0 26	4 85	1 73
FAL8	1	0 43	1.00	11.55	6 89	4.63	2.38	36 10	0 40	18.00	1 84
FALsub	12	0 65	7 46	44 24	4.32	29.05	4.58	25.78	0 59	7 22	1.35
FRA1	17	0 72	10.76	21.63	13 25	12 05	2.10	25.96	0.48	6.07	1 91
FRA3	2	0 68	1 28	7.29	0 64	3.91	1.08	25.85	0 28	3.25	0 41
FRA8	3	0 58	2 18	7 30	2 73	20.71	4.63	31.20	0.23	0 57	1.17

Code	Count	Max	N2	N Opt (µg N L-1)	N Tol (µg N L-1)	P Opt (µg P L-1)	P Tol (µg P L-1)	Sal Opt (ppt)	Sal Tol (ppt)	Turb Opt (NTU)	Turb Tol (NTU)
FRAgeo	14	0.47	10 65	91 26	10.25	33.92	2.81	15 67	2.15	8 43	3 53
FRAque	23	0.78	15.76	23.32	11 01	7 27	1 33	25.20	0.30	7.51	2 00
FRAshu	6	0 43	4 40	46.37	5 31	15.34	2.82	18 65	0.71	10.83	1.13
FRAvir	8	0.36	6.68	21.89	6 41	6 48	1.73	20.63	0.49	11 60	1.19
GRA2	4	0 75	3 33	7 51	1 44	5.97	3 08	26 43	0 16	4.43	0.48
GRA3	3	1.25	1 32	12 94	1 93	37 27	6 84	32 99	0.17	1.19	0.62
GRAarc	7	0 35	4 79	96 94	8 22	30 24	2 08	30.01	0 50	27 99	4.31
GRAmac	15	0 68	8 94	8.39	5 05	8 04	3.18	26 62	0 32	4.18	1.19
GRAmar	10	0 78	8 00	17.29	5.02	22.54	6.88	28 64	0 24	6.63	0.84
GRAoce	27	1 17	19 81	10 42	4 03	8 95	2 80	26.77	0.30	5.86	1 31
GRAsub	16	0 98	10 90	6.34	3 26	4.20	1 57	27 14	0.23	3 42	0.98
GYRbal	24	1 13	12.64	50 48	14.95	22.27	4 30	25 73	0 53	11 04	2.04
LIC1	6	0.41	4.19	3.56	2.91	8.97	7 14	26.99	0.16	3.66	1.27
LIC1a	10	0 41	7 29	24 89	23 28	18 49	4 86	28.26	0.25	3.80	2.87
MAS2	4	0 74	2 92	2 84	2 35	3.79	0.53	30 85	0.22	11.04	0.57
MAS2a	7	0 39	5 10	6.04	10.23	17 59	3.55	33 77	0 13	8.80	1.12
MAS3	4	0 64	2 85	6.35	1 61	3 92	0.67	30.46	0.24	8 12	2.07
MAS4b	1	0.60	1 00	14 30	6 89	11 18	2.38	35.55	0.40	5.50	1 84
MAS5	4	0 30	2 88	5.73	2 08	4 08	1 06	26 94	0 25	2.70	1.01
MAS6	2	0 54	1 59	1 87	2 02	2 91	0 70	23.08	0.19	3.65	1 25
MEL1	11	1 24	7 01	17 39	3 13	3 87	0 74	29.43	0 33	13.42	4.41
NAV1	11	0 75	7 71	17 80	3 56	10 98	3 47	26.97	0 35	8 03	1 37
NAV10	25	0.71	16.82	11.43	5.66	8.78	2 20	25 61	0 43	5.12	2.22
NAV12	9	0.81	6.44	6 63	2.95	3.17	0 75	28.74	0 24	4.36	1.67
NAV14	4	0.45	3.05	2 52	4 91	5 01	2.52	26 39	0 19	4 13	1.92
NAV16	7	0 87	4 20	8 45	12.43	4 83	2 41	23.36	0.37	3.87	1 47
NAV3	25	0 99	16 50	37 44	13 63	17.04	2 69	28.27	0 50	7 58	2.18
NAV30	2	0 69	1 27	31 73	1.16	14 57	1 27	34.12	0.05	23 61	0.23
NAV34	1	0 54	1 00	112 00	6.89	10 16	2 38	9.55	0 40	9.00	1.84
NAV35	4	0 34	3.33	41 05	16.71	25 83	0 92	30 02	0 25	7.05	2.27
NAV36	1	0 56	1.00	14.96	6.89	55 97	2 38	33 65	0 40	1.00	1.84
NAV4	21	1 02	11 69	32 75	15 51	13 35	3 38	25.99	0 76	10 70	2.11
NAV7	30	1.18	22.39	32.40	11.35	20.68	3 18	27.95	0.34	8.04	2.71
NAVper	34	1 12	25 59	21 31	7.95	13 82	2.53	26.39	0 40	7 34	1 53
NAVryn3	8	0 94	4 30	485 04	26 25	66 44	2 34	21.72	0 78	33 04	2.04
NIT11a	1	0.57	1 00	3001.37	6.89	81 73	2.38	11.35	0.40	73 00	1.84

Code	Count	Max	N2	N Opt (µg N L-1)	N Tol (µg N L-1)	P Opt (µg P L-1)	P Tol (µg P L-1)	Sal Opt (ppt)	Sal Tol (ppt)	Turb Opt (NTU)	Turb Tol (NTU)
NIT2	12	0 51	8 96	33 71	6 23	24 89	3 42	26.58	0 60	21 70	2.32
NIT6	17	0 71	11 88	75.91	10 54	20.41	2.21	21.36	1 02	12 50	2.53
NIT6a	12	0 47	8 61	153.19	10 49	24.18	3 01	21.43	1 10	15 47	2 00
NITlan	10	0.51	6 98	21 93	12 93	8.97	2.97	25 64	0.31	7.49	0 99
NITpan	9	0 99	5 42	5.23	4 11	4 12	1.73	25.83	0 41	7.33	0 85
NITpan1	17	0.88	11.15	7.87	2.78	11 41	2 34	25.71	0.38	3 46	1.18
NITscal	31	0.79	20 45	26 14	8 05	11 61	3 13	24.85	0.52	8 80	2 35
NITval	39	1.07	25 03	17 36	11 74	22 99	3 38	27.52	0 43	5 55	2.35
OPE3	34	0.84	26.40	25.16	12.59	16 09	2 79	26.08	0.43	6.66	2 56
OPEbur	32	1 64	20 91	25 56	14 57	19 62	2 47	19.21	1.40	7 73	2 82
OPEbur2	2	0 90	1 45	38.61	19 83	3 55	6 25	31.77	0.31	4 81	1.56
OPEgue	35	1 46	26 50	26 04	10 45	18.01	3 67	21.47	1 18	7 72	2.20
OPEmar	40	1 35	29.22	28 22	12 29	19 70	3.72	23.48	0 99	8.04	1 94
PARsul	13	0 76	11.45	23 94	12.40	15.79	2 61	26.02	0.47	11 98	1 80
PLAdel	37	1.15	28 82	42 88	12 27	15 79	2.41	24.28	0 53	6 81	2.27
PLAdel3	22	1 14	16 05	50.90	10 36	13 96	2 06	24 03	0 46	7 68	2.14
PLAdel4	10	0 80	7 00	332.79	7 24	33 02	3 65	24.09	1 65	18.25	3 19
PLAdis	10	0 81	6.53	17 03	9 76	17 65	3 66	23.26	0 54	2 78	1 98
PLAhau	41	1 01	32 94	32.26	12 31	23.26	3.10	26.31	0 46	6 11	1 93
PLAlan	14	0 90	8 94	11.08	10.07	11.30	1 79	22.33	0.41	6 17	2.24
PLApol2	5	0.39	3.57	71 11	10 14	7 19	0 68	28.69	0.52	10 61	2 05
PSEper	14	0.54	11.29	49 15	15 63	44 42	4.93	28.10	0 86	6.92	2 73
RHA2	6	0.48	4.10	3 76	1 63	3 43	0.50	24.82	0 09	5 22	0 65
RHA2a	9	0.48	6.61	4.83	1.78	4.86	1 00	30 05	0.23	5 80	1.12
RHA3	7	0 51	4 18	5 94	3 35	3.97	0 56	24.15	0 34	5 80	0 73
RHOacu	23	1 03	15.12	8.41	2 95	6.67	1 47	23.43	0 43	4 28	1 32
rVIK5	3	0 41	2.23	50 53	2 21	13 46	1 24	35.08	0 11	37 54	1.66
STA4	2	0.34	1.99	21.77	0 72	55.97	2 38	36.47	0.13	13 05	18.35
SYN1	12	0 33	9.25	19 41	5.19	17 85	3 62	19 75	0.57	5 12	1.51
SYN3	4	0.81	2.30	12 14	0.84	8 24	0.96	35.67	0.01	5 66	1 00
SYNcam	8	0 40	6 41	14 37	5.81	22.27	6.39	30.72	0 18	9.37	0 69
SYNfas	29	0.96	20.73	21 39	8 24	10 49	3.05	22.23	0 50	6.59	1 44
SYNfas1	2	0 48	1 81	37.22	4 67	20.32	18.74	28.47	0 23	7 15	0.38
UNK1	17	0.57	13 18	53.71	10 48	31.91	4 57	27 42	0.42	11 91	1.95
UNK100c	10	0.86	6 74	555 35	7 42	76 17	0.66	26 16	1.20	6.45	3.81
UNK107	14	1.24	9.18	71.73	10.96	13 62	3 40	29.58	0.33	9.00	2.41

Code	Count	Max	N2	N Opt (µg N L-1)	N Tol (µg N L-1)	P Opt (µg P L-1)	P Tol (µg P L-1)	Sal Opt (ppt)	Sal Tol (ppt)	Turb Opt (NTU)	Turb Tol (NTU)
UNK111	1	0.35	1.00	4 81	6.89	13.71	2.38	33.75	0.40	32.50	1 84
UNK116a	1	0.39	1 00	36.67	6.89	64 33	2.38	35.55	0.40	2.00	1.84
UNK117	1	0 31	1 00	36.35	6 89	16.91	2.38	33.85	0.40	24.50	1.84
UNK14	1	0 40	1.00	14.30	6 89	11.18	2.38	35 55	0.40	5.50	1.84
UNK19	6	0.42	4.68	13.99	4.42	6.64	1.25	22 38	0.43	6.10	1 91
UNK19a	10	0.68	6.97	13 02	9.96	11.18	2.19	30 48	0.21	5.06	2 17
UNK19b	27	0 82	19.12	23.22	9.96	31.03	4.41	28 92	0.32	5.95	1.68
UNK19d	5	0 52	3.73	43 28	2.70	37.25	1.59	34 13	0.04	2.77	3 28
UNK23	17	0 53	11 64	10.68	1.73	7.08	2 40	29.54	0.22	3 99	1.29
UNK24	13	0.35	10.30	6 52	5.01	8 45	1.94	27.28	0 24	4 28	1.86
UNK27	15	0.86	11.04	38 30	11.50	9 91	2 54	23.02	0 84	8 41	2.18
UNK27a	10	0.72	6 67	21 96	5.00	9.23	1.24	21.32	0 53	5.16	1.61
UNK28	5	0 41	3 69	37 57	1.96	13.60	1.24	20.70	0.63	8.07	1.86
UNK30	35	0.96	24.99	19.54	9 67	10.71	2 39	26.06	0.32	6 21	2.35
UNK31a	5	0 58	3 67	32 67	7.60	112.93	1.68	34 17	0.02	4.08	4.03
UNK4	9	0.43	7 24	23.47	3.33	15 39	4 69	28 84	0.54	17.11	2.99
UNK43	8	0 54	6.82	9.47	6 70	7.05	1.59	16.95	0.52	5.40	0.74
UNK5	42	1 35	32 77	30.24	11 60	18.91	3.45	28 64	0.50	7.09	2.45
UNK57	3	0.44	2 19	214.50	235 76	36.10	16 59	30.31	0.19	14 91	5 56
UNK62	18	0.69	9.63	309 37	17.89	40 28	3.45	31.66	0 16	9 94	3.32
UNK69	11	0 59	7 16	4.70	10.54	6.88	2 43	25.47	0 25	3 99	2.29
UNK69a	2	1.04	1 53	4696.32	0 13	196.03	0 01	34.05	0.01	38 62	0.19
UNK7	30	1 04	19 97	27.38	12 13	9.17	2 75	25.23	0.43	6.90	1 89
UNK80	13	0 72	9.15	11 74	4.63	11.43	1.53	22.99	0 53	3.58	0.82
UNK87a	2	0.60	1.70	1.37	1.44	23.94	0.69	27.04	0 24	4.29	5.27
UNK89	5	0.40	3.42	39.10	18.37	15.10	2.45	15.79	0 71	4.67	2.85
VIK10	5	0.58	3.61	243.19	17.49	73.41	0.97	33 88	0 04	2.95	4.80
VIK3	8	0.66	5.64	54 95	8.96	4.27	0 91	31 82	0.12	9.62	1.86

Species list ordered by scientific name

Species name	Code
Achnanthes brevipes	ACHbre
Achnanthes cf. *subexigua*	OPE3c
Achnanthes fogeddii	ACH1
Achnanthes minutissimum	ACHsub1
Achnanthes sp. 1	ACH15
Adlafia frenotii	NAVryn6
Amphora acutiuscula	AMPcof
Amphora acutiuscula var. 1	AMP4
Amphora copulata	AMP11c
Amphora sp. 1	AMP23
Amphora veneta	AMPven
Aulacoseira cf. *italica*	AULita
Aulacoseira distans	CEN16a
Aulacoseira distans var. 1	CEN17
Aulacoseira granulata	AULgra
Aulacoseira valida	AULval
Bacillaria paxillifer	NITscal
Caloneis bacillum	NAV57
Caloneis bacillum var. 1	NAV61
Caloneis bacillum var. 2	NAV57a
Caloneis bacillum var. 3	NAV66
Cavinula cf. *pseudoscutiformis*	COC13
Cocconeis cf. *neothumensis*	COC15
Cocconeis cf. *placentula*	COCpla
Cocconeis disculus	COCdis
Cocconeis pediculus	COC8
Cocconeis peltoides	ACH3
Cocconeis scutellum var. *scutellum*	COCscu
Cocconeis sp. 1	COC8a
Cocconeis sp. 2	COC15a
Craticula salsuginosa	NAVryn7
Craticula salsuginosa var. 1	UNK87c
Cyclotella meneghiniana	CEN15
Cyclotella meneghiniana var. 1	CYCmen
Cyclotella striata	CYCstr
Cymbella sp. 1	AMP22
Cymbella sp. 2	CYMasp3
Diatomella cf. *balfouriana*	UNK37b
Diploneis subovalis	DIP11
Encyonema sp. 1	AMP18a
Eunotia flexuosa	UNK57b
Eunotia naegelii	EUNnae
Fragilaria capucina	FRA8
Fragilaria capucina var. 1	FRAcap2
Fragilaria capucina var. 2	UNK304
Fragilaria cf. *sopotensis*	ACH4c
Fragilaria cf. *virescens*	FRA3
Fragilaria sp. 1	FRA7
Frustulia cf. *subantarctica*	UNK87d

Appendix 5: Macquarie Island diatom species list and raw data

- Macquarie Island diatom species list ordered by scientific name
- Macquarie Island diatom species list ordered by code
- Macquarie Island species occurrences

Frustulia cf. *subantarctica* var. 1	FRUrho
Gomphonema affine var. *affine*	GOMang3
Gomphonema angustatum	GOMang
Gomphonema parvulum	GOMang1
Gomphonema sp. 1	GOMang2
Kobayasiella subantarctica	ACH41
Navicula arvensis	ACH38
Navicula contenta	NAVcon
Navicula gottlandica	NAVgot
Navicula mutica var. mutica	NAVmut
Navicula nivaloides	NAVniv
Navicula recens	NAV10
Navicula sp. 1	NAV63
Navicula viridula	NAVvir
Naviculadicta seminulum	ACH25a
Naviculadicta seminulum var. 1	ACH33
Naviculadicta seminulum var. 2	ACH25c
Nitzschia cf. *gracilis*	NIT6
Nitzschia cf. *hungarica*	NIT6c
Nitzschia cf. *palea*	FRA12
Nitzschia sp. 1	NIT4b
Nitzschia sp. 2	NIT6a
Opephora cf. *guenter-grassii*	OPEgue
Opephora cf. *pacifica*	OPEbur
Opephora krumbeinii	CEN5
Petroneis sp. 1	COC13a
Pinnuavis cf. *elegans*	NAV61a
Pinnularia bottnica	NAV50
Pinnularia bottnica var. 2	NAV60
Pinnularia bottnica var. 1	NAV54b
Pinnularia cf. *rabenhorstii* var. *rabenhorstii*	NAV65
Pinnularia decrescens var. *kerguelensis*	PIN4b
Pinnularia divergentissima var. *divergentissima*	NAV50c
Pinnularia divergentissima var. *divergentissima*	PLAfre4
Pinnularia rabenhorstii var. *subantarctica*	PIN5
Pinnularia sp. 1	PIN4
Pinnularia subantarctica var. *elongata*	NAV55
Pinnularia subantarctica var. *elongata*	NAV61b
Planothidium cyclophorum	ACHpse4
Planothidium cyclophorum var. 1	ACHpse5
Planothidium cyclophorum var. 2	ACHpse3
Planothidium delicatulum	ACH26
Planothidium delicatulum	PLAdel
Planothidium dispar	ACH5
Planothidium lanceolatum	PLAfre3
Planothidium quadripunctatum	PLAhau
Planothidium quadripunctatum	PLAhau3
Planothidium renei	ACH25
Psammothidium abundans	ACHsub2
Psammothidium oblongellum	PLAmar/UNK19c
Psammothidium oblongellum var. 1	ACH42
Pseudogomphonema septentrionale var. *septentrionale*	PSEsep

Rhoicosphenia marina	UNK70a
Stauroforma exiguiformis	FRA3a
Stauroneis aff. *phoeniceuferon*	UNK309
Stauroneis circula	ACH32
Stauroneis sp. 1	ACHsub
Staurosira cf. *alpestris*	FRA8a
Staurosira martyi	OPE9
Staurosira venter	CEN16
Stenopterobia curvula	UNK308a
Surirella cf. *tenuis*	UNK308
Synedra cf. *camtschatica*	SYNcam
Unknown sp. 1	NAV32c
Unknown sp. 2	ACH38a
Unknown sp. 3	NAV67
Unknown sp. 4	NAVryn5
Unknown sp. 5	UNK302a
Unknown sp. 6	UNK310
Unknown sp. 7	UNK10
Unknown sp. 8	UNK100b
Unknown sp. 9	UNK117a
Unknown sp. 10	UNK117c
Unknown sp. 11	UNK57

Species list ordered by code

Species name	Code
Achnanthes fogeddii	ACH1
Achnanthes sp. 1	ACH15
Planothidium renei	ACH25
Naviculadicta seminulum	ACH25a
Naviculadicta seminulum var. 2	ACH25c
Planothidium delicatulum	ACH26
Cocconeis peltoides	ACH3
Stauroneis circula	ACH32
Naviculadicta seminulum var. 1	ACH33
Navicula arvensis	ACH38
Unknown sp. 2	ACH38a
Kobayasiella subantarctica	ACH41
Psammothidium oblongellum var. 1	ACH42
Fragilaria cf. *sopotensis*	ACH4c
Planothidium dispar	ACH5
Achnanthes brevipes	ACHbre
Planothidium cyclophorum var. 2	ACHpse3
Planothidium cyclophorum	ACHpse4
Planothidium cyclophorum var. 1	ACHpse5
Stauroneis sp. 1	ACHsub
Achnanthes minutissimum	ACHsub1
Psammothidium abundans	ACHsub2
Amphora copulata	AMP11c
Encyonema sp. 1	AMP18a
Cymbella sp. 1	AMP22
Amphora sp. 1	AMP23
Amphora acutiuscula var. 1	AMP4
Amphora acutiuscula	AMPcof
Amphora veneta	AMPven
Aulacoseira granulata	AULgra
Aulacoseira cf. *italica*	AULita
Aulacoseira valida	AULval
Cyclotella meneghiniana	CEN15
Staurosira venter	CEN16
Aulacoseira distans	CEN16a
Aulacoseira distans var. 1	CEN17
Opephora krumbeinii	CEN5
Cavinula cf. *pseudoscutiformis*	COC13
Petroneis sp. 1	COC13a
Cocconeis cf. *neothumensis*	COC15
Cocconeis sp. 2	COC15a
Cocconeis pediculus	COC8
Cocconeis sp. 1	COC8a
Cocconeis disculus	COCdis
Cocconeis cf. *placentula*	COCpla
Cocconeis scutellum var. *scutellum*	COCscu
Cyclotella meneghiniana var. 1	CYCmen
Cyclotella striata	CYCstr
Cymbella sp. 2	CYMasp3

Diploneis subovalis	DIP11
Eunotia naegelii	EUNnae
Nitzschia cf. *palea*	FRA12
Fragilaria cf. *virescens*	FRA3
Stauroforma exiguiformis	FRA3a
Fragilaria sp. 1	FRA7
Fragilaria capucina	FRA8
Staurosira cf. alpestris	FRA8a
Fragilaria capucina var. 1	FRAcap2
Frustulia cf. subantarctica var. 1	FRUrho
Gomphonema angustatum	GOMang
Gomphonema parvulum	GOMang1
Gomphonema sp. 1	GOMang2
Gomphonema affine var. *affine*	GOMang3
Navicula recens	NAV10
Unknown sp. 1	NAV32c
Pinnularia bottnica	NAV50
Pinnularia divergentissima var. *divergentissima*	NAV50c
Pinnularia bottnica var. 1	NAV54b
Pinnularia subantarctica var. *elongata*	NAV55
Caloneis bacillum	NAV57
Caloneis bacillum var. 2	NAV57a
Pinnularia bottnica var. 2	NAV60
Caloneis bacillum var. 1	NAV61
Pinnuavis cf. *elegans*	NAV61a
Pinnularia subantarctica var. *elongata*	NAV61b
Navicula sp. 1	NAV63
Pinnularia cf. *rabenhorstii* var. *rabenhorstii*	NAV65
Caloneis bacillum var. 3	NAV66
Unknown sp. 3	NAV67
Navicula contenta	NAVcon
Navicula gottlandica	NAVgot
Navicula mutica var. *mutica*	NAVmut
Navicula nivaloides	NAVniv
Unknown sp. 4	NAVryn5
Adlafia frenotii	NAVryn6
Craticula salsuginosa	NAVryn7
Navicula viridula	NAVvir
Nitzschia sp. 1	NIT4b
Nitzschia cf. *gracilis*	NIT6
Nitzschia sp. 2	NIT6a
Nitzschia cf. *hungarica*	NIT6c
Bacillaria paxillifer	NITscal
Achnanthes cf. *subexigua*	OPE3c
Staurosira martyi	OPE9
Opephora cf. *pacifica*	OPEbur
Opephora cf. *guenter-grassii*	OPEgue
Pinnularia sp. 1	PIN4
Pinnularia decrescens var. *kerguelensis*	PIN4b
Pinnularia rabenhorstii var. *subantarctica*	PIN5
Planothidium delicatulum	PLAdel
Planothidium lanceolatum	PLAfre3
Pinnularia divergentissima var. *divergentissima*	PLAfre4

Planothidium quadripunctatum	PLAhau
Planothidium quadripunctatum	PLAhau3
Psammothidium oblongellum	PLAmar/UNK19c
Pseudogomphonema septentrionale var. *septentrionale*	PSEsep
Synedra cf. *camtschatica*	SYNcam
Unknown sp. 7	UNK10
Unknown sp. 8	UNK100b
Unknown sp. 9	UNK117a
Unknown sp. 10	UNK117c
Unknown sp. 5	UNK302a
Fragilaria capucina var. 2	UNK304
Surirella cf. *tenuis*	UNK308
Stenopterobia curvula	UNK308a
Stauroneis aff. *phoeniceuferon*	UNK309
Unknown sp. 6	UNK310
Diatomella cf. *balfouriana*	UNK37b
Unknown sp. 11	UNK57
Eunotia flexuosa	UNK57b
Rhoicosphenia marina	UNK70a
Craticula salsuginosa var. 1	UNK87c
Frustulia cf. *subantarctica*	UNK87d

Macquarie Island diatom species occurrences (as % relative abundance)

Spp	MacIs1	MacIs2	MacIs3	MacIs4	MacIs5	MacIs6	MacIs8	MacIs9	MacIs11	MacIs12	MacIs13	MacIs14	MacIs15	MacIs16	MacIs17	MacIs18	MacIs19
ACH1	1.17	0 75	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0.00
ACH15	4.66	0 50	0 00	0.34	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0 00	0.00	0.00
ACH25	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0.46	0 49	0 00	1 96	0 00	0 00	0.00	0.00	0 00
ACH25a	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	1 94	0.00	0 00	0.32	0.00	0 00	0 00	0.00
ACH25c	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0.00	0.00
ACH26	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0.25	0 00
ACH3	0 00	0.00	0.00	3.72	1.04	0 24	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0.00
ACH32	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	1 94	0 00	0 00	0.00	0 00	0.00	1 49	0.00
ACH33	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00
ACH38	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0 00	8.50	0.00	0 00
ACH38a	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	7.25	0 00	0.00
ACH41	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0.00
ACH42	0 00	0 00	0 00	0.00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00
ACH4c	0 23	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0.00
ACH5	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0.00	0.00
ACHbre	0.00	1 00	0 00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0 00
ACHpse3	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0.97	0 00	0 00	0 00	0 00	0.00	0.00	0.00
ACHpse4	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	9.71	0 00	0.00	0.00	0 00	0.00	0.00	0.00
ACHpse5	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	2.67	0 00	0.00	0.00	0 00	0.00	0.00	0 00
ACHsub	7.46	9.00	0.15	0 17	0 00	7 28	62 50	1 75	0 68	9 95	1.90	2.94	0 00	15 95	0 00	9.70	23 88
ACHsub1	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0.98	0 00	3.19	0.00	1.24	3 55
ACHsub2	0.00	0 00	0.00	0 00	0 00	0.00	0 00	0.00	9.36	2 91	95.06	12.75	0.97	67.20	4.00	11 44	61.47
AMP11c	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.23	0.49	0 00	0 00	0.32	0 00	0.00	0.00	0.00
AMP18a	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	1 70	0 00	2 45	0.32	0 00	0.00	0 00	0.00
AMP22	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0.65	0.46	0 00	0 00	0.00
AMP23	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0.00
AMP4	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	3 40	0 00	0 00	0.00	0.00	0 00	0 25	0.00
AMPcof	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0 00
AMPven	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0 00
AULgra	2.33	0.00	0.00	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0.00
AULita	6 29	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0.00
AULval	5 13	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0.00

Spp	MacIs1	MacIs2	MacIs3	MacIs4	MacIs5	MacIs6	MacIs8	MacIs9	MacIs11	MacIs12	MacIs13	MacIs14	MacIs15	MacIs16	MacIs17	MacIs18	MacIs19
CEN15	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00
CEN16	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	1 46	0.00	3.92	0.00	0 00	50 00	0 00	0.00
CEN16a	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	1.14	0 00	9.06	0 00	9.75	1.00	0.00
CEN17	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0 00	42 65	0.00	3.64	0 00	0 00	0.00
CEN5	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00
COC13	1 40	0.00	0.00	0 00	0.00	0 00	2 50	0 25	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 24
COC13a	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0.32	0 23	7.50	6 47	0 00
COC15	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0.00
COC15a	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 65	0.00	0.00	0.00	0 00
COC8	0.00	0.00	0 00	0 00	0.00	49 76	0.00	0 00	2 97	5 10	0.00	0.00	1.62	0.00	0 00	0 50	0.00
COC8a	0 00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0 00	1 29	0 23	0 00	0 50	0.00
COCdis	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0.00
COCpla	7.46	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0.00
COCscu	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	0.00
CYCmen	0.23	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0.00
CYCstr	0.23	0 00	0 00	0 00	0.00	0.00	0.75	0 25	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0.00
CYMasp3	0.00	0.00	0 00	0 00	0 00	0.00	0 25	5 50	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0.00
DIP11	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 23	0 00	0 00	0.00	0.32	0.00	0 00	0 00	0.00
EUNnae	0.00	0 00	0 00	0 00	0.00	0 00	0.00	1 25	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0.00
FRA12	0.00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0.00
FRA3	0.00	1.00	0 00	0 00	0.00	0.00	0 00	0 00	0 23	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0.00
FRA3a	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0 97	0.00	1 00	0.00	0.00
FRA7	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0.00
FRA8	0.00	9 50	97.73	93.24	97 93	0 00	2 25	14 25	0 91	22 33	0.00	2.45	1.62	1.82	0 00	1.24	0.00
FRA8a	0.00	0 00	0.00	0 00	0.00	0 00	0.00	0.00	1 14	4.13	0.00	0.00	0.00	0.00	0.00	0.00	0 00
FRAcap2	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	79 45	1 21	0 00	2 45	0.00	0 00	0 00	0.00	0.00
FRUrho	0 00	0 00	0.00	0.00	0.00	0.00	1.75	3.25	0 00	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0.00
GOMang	0.00	0 00	0 00	0 00	0.00	4 85	0 00	2.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00
GOMang1	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0 00	0.00	0 00	0.00	0 00	0 00	0.00	0 00
GOMang2	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	0.24	0.00	0.00	0.00	0 23	0.00	0.00	0.00
GOMang3	0.00	0 00	0 00	0 00	0.00	0.00	0 00	0.00	2.05	1.70	0 00	0.00	0.00	0 00	0.00	0.00	0 00
NAV10	1.40	0.00	0.00	0 00	0.00	0.24	0 00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00
NAV32c	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.86	0.65	0 23	0 25	0 25	0.71
NAV42	1.86	4.00	0.60	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0.00
NAV50	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0.23	0 00	0.75	0.00

Spp	MacIs1	MacIs2	MacIs3	MacIs4	MacIs5	MacIs6	MacIs8	MacIs9	MacIs11	MacIs12	MacIs13	MacIs14	MacIs15	MacIs16	MacIs17	MacIs18	MacIs19
NAV50c	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0.98	0.00	0 00	0.00	0.00	0 00
NAV54b	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	1.14	0.00	0.00	0.00	0 75	0 00	0 00
NAV55	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.49	0.00	2.94	1.94	0.00	1 00	0 00	0 00
NAV57	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	2.91	0.76	3 43	0 00	0 00	0.00	0.25	0 00
NAV57a	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	1 94	0 00	0.00	0 00	0 00
NAV60	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00
NAV61	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0 00
NAV61a	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0 00	0 00
NAV61b	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0.00
NAV63	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0 98	0 00	0.46	3.00	0.00	0 00
NAV65	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0.50	0.00	0 00
NAV66	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 00
NAV67	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0 00
NAVcon	0.00	0 00	0 00	0.00	0.00	0.00	3 00	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00
NAVgot	0.00	0.00	0 00	0 00	0 00	0.00	1.00	5 75	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00
NAVmut	0.00	0 00	0 00	0 00	0.00	0.00	1.50	1 50	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0 00
NAVnıv	0.00	0.00	0.00	0 00	0 00	0.00	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00
NAVper2	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00
NAVryn5	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	1.21	0 00	0.00	0 00	0 00	0 00	0.25	0 00
NAVryn6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0 00
NAVryn7	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00
NAVvır	0 00	0.00	0.00	0.00	0.00	0 00	0.00	1.25	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00
NIT4b	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0.49	0.00	0 00	0.00	0.00	0 00
NIT6	0.00	0.00	0.00	0.00	0.00	0.49	0 00	0 00	0.00	1.21	0.00	0.00	0.00	0.23	0.00	0 00	0.00
NIT6a	0.00	0.00	0.00	0.00	0 00	1 21	0.00	0 00	0.00	0.00	0 00	0.00	1.29	0.00	0.50	0.00	0.00
NIT6c	0.00	0.00	0 00	0.00	0 00	0 00	0.00	0 00	0 00	1 21	0 00	0 00	0.00	0.00	0.75	0 00	0.00
NITscal	0.00	0.00	0.00	0 00	0 00	0 00	0.25	0.00	0.00	0 00	0 00	0 00	0.32	0 00	0.00	0.00	0.00
OPE3c	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	3.42	1.00	0 00	9.93
OPE9	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	1.94	0.00	0.00	3.88	0 23	0.50	0.00	0.00
OPEbur	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 00
OPEgue	12 82	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0 68	0 00	0 00	0.00	0.00	0 46	0 00	0 00	0.00
PIN4	1.17	1.00	0.00	0 00	0 00	0 24	1.50	0 25	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0 00
PIN4b	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0.00
PIN5	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	1.29	0 00	1 25	0.00	0 00
PLAdel	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Spp	MacIs1	MacIs2	MacIs3	MacIs4	MacIs5	MacIs6	MacIs8	MacIs9	MacIs11	MacIs12	MacIs13	MacIs14	MacIs15	MacIs16	MacIs17	MacIs18	MacIs19
PLAfre3	17.72	15.75	0.60	1.01	0.21	34.47	1.00	0 00	0 46	9.71	0.00	0 00	1.94	0.00	0 00	0.25	0 24
PLAfre4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0.00
PLAhau	0 00	2.00	0.00	0.17	0.00	0.00	0.00	0.00	0.00	2 67	0 00	0.00	0.32	0.00	0 00	59.20	0 00
PLAhau3	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0 00
PLAhau3b	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0 00	0.00
PLAmar	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	1.24	0.00
PLApol2	0 00	1 75	0 00	0.00	0.00	0 49	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0.00
PSEsep	3 03	4 00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0.00
SYN5	16 78	47 00	0.76	0 68	0.41	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0.00
SYNcam	0.00	0 00	0 00	0.00	0 00	0.00	0 25	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0.00
UNK10	0.00	0 00	0 00	0.00	0.00	0.00	3.00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0 00
UNK100b	4.66	0.00	0 15	0 00	0.21	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00
UNK117a	0.70	0.00	0.00	0.51	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0 00
UNK117c	0.00	0 00	0 00	0 00	0.00	0.00	0 00	4 50	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0 00
UNK19c	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0 00
UNK302a	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0 00	0 00	0.24	0.00	0 00	0.00	0.00	0 00	0.00	0 00
UNK304	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0 00	0.00
UNK308	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0.50	0.00	0 00
UNK308a	0 00	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0 00
UNK309	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	1 21	0 00	0 98	0.00	0 00	0.00	0.00	0 00
UNK310	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	64.72	0 00	0.00	0.00	0.00
UNK37b	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0.00	0 46	0.00	0.00	0.49	1 62	0.23	0.00	1.99	0.00
UNK57	0 00	0.00	0.00	0 00	0.00	0 00	0 00	0.25	0 00	0.00	0.00	0.00	0 00	0.91	0.00	0 00	0.00
UNK57b	0 00	0.00	0.00	0.00	0.00	0 00	14 75	56 25	0 00	0 00	0 00	1.96	0.00	0 00	1.00	0.00	0 00
UNK70a	0 00	1 50	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0.00
UNK87c	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	1 94	0 00	7.35	0.00	0.00	0 50	0.00	0 00
UNK87d	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0 00

Spp	MacIs20	MacIs21	MacIs22	MacIs23	MacIs24	MacIs25	MacIs26	MacIs27	MacIs28	MacIs29	MacIs30	MacIs31	MacIs32	MacIs33	MacIs34	MacIs35
ACH1	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0 00	0.00	0 00
ACH15	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0 00	0.00
ACH25	0.00	0.00	0.64	0.00	0 00	0 00	0 00	0.00	28 80	0.00	0 00	0 00	0 00	0 00	0.00	0.00
ACH25a	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0 00	0.00
ACH25c	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0 00	0 00
ACH26	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00
ACH3	0.00	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0 00
ACH32	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	1.20
ACH33	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00
ACH38	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00
ACH38a	0 00	0.00	0.32	0 00	0 00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00
ACH41	0.00	0.00	0.00	0 00	0.00	8.73	0 00	3.84	2.07	1.95	0.00	1.69	1 13	0.00	0.84	0.00
ACH42	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0.69	1.95	0.67	2 65	0 28	0 00	0.00	0.00
ACH4c	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0.00
ACH5	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00
ACHbre	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00
ACHpse3	0 00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	1.46	0.22	0.00	0 28	1.90	1.67	1.44
ACHpse4	0.00	0.22	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0 00
ACHpse5	0 00	0.00	0.32	0.00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00
ACHsub	17 06	0 00	0 00	13.30	9.00	0 00	0 00	0 00	0 00	7 06	4 43	3 13	3.10	2 11	0 00	0 00
ACHsub1	2.35	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0.00
ACHsub2	59 71	0.00	1.92	27.52	23.75	12 47	19 80	13 65	0 00	1 46	0 44	4.34	13.52	12 66	16 91	1 92
AMP11c	0 00	0.00	0.00	0.00	0.00	0.00	1.96	0 00	0 00	0.00	0.00	0.00	0 56	0 00	0 42	0 00
AMP18a	0.59	0 00	0 64	0 23	1 75	6.98	0.49	3 84	0.00	6.81	2.00	0 00	1 69	0.00	0 63	0 24
AMP22	0.00	0.00	0.32	0 69	0 00	0.75	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0 42	0 00	1 44
AMP23	0 00	0 00	0.96	0 00	0.00	13 72	2 69	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00
AMP4	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0 00
AMPcof	0.00	1.54	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.56	0.00	0 00	0 00
AMPven	0.00	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0.00	0 00
AULgra	0 00	0 00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0.00
AULita	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0 00
AULval	0.00	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0.00

Spp	MacIs20	MacIs21	MacIs22	MacIs23	MacIs24	MacIs25	MacIs26	MacIs27	MacIs28	MacIs29	MacIs30	MacIs31	MacIs32	MacIs33	MacIs34	MacIs35
CEN15	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00
CEN16	0.00	0 00	0.00	4.59	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CEN16a	1 18	0.00	0.32	4 36	0 75	0.00	20 05	13 01	0 00	38 93	11 09	75.18	3.38	0 00	0 00	0.48
CEN17	0.00	0.00	0.00	0.69	0 00	0.25	2.44	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0 00	0.00
CEN5	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00
COC13	0 00	0 00	0.00	0 00	0.00	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0 00
COC13a	0.00	0.00	0 00	2.52	0.25	0.25	13.45	0.00	0.00	0 73	1 55	0.00	11.27	8.44	8.14	2.64
COC15	0 00	1.10	0.00	0 00	0 00	0.50	0 00	0.00	0 00	0.00	0.00	0.00	0 28	0.00	0.00	0 00
COC15a	0.00	0.00	5.45	0 00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 21	0 00
COC8	0 00	44 93	17 63	0 00	0.00	2.49	0 00	0 00	1.38	0.00	0.00	0.00	9.30	0.00	0.00	0.00
COC8a	0.00	5 51	1 92	0.00	0.00	0 25	0.00	0.00	0 69	0 00	0.00	0.00	0 00	0.00	0.00	0.00
COCdis	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00
COCpla	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00
COCscu	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0.00
CYCmen	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0 00
CYCstr	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0 00
CYMasp3	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0.00
DIP11	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0 63	1.92
EUNnae	0 00	0.00	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FRA12	0.00	0.00	2 24	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00
FRA3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0 00	1.41	0 84	4.18	6.97
FRA3a	0.00	0 00	2 24	0.23	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.21	0 63	2 88
FRA7	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00
FRA8	0.29	38.11	32.05	1 61	1 00	1.50	2 20	0.00	9.22	5 60	2 22	0.00	7.61	48 52	39.46	20.91
FRA8a	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	21 31	11.48	31.25
FRAcap2	0 00	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0 00
FRUrho	0 00	0.00	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0.00
GOMang	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00
GOMang1	0 00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0.00
GOMang2	0.00	3.74	8 01	0 00	0 00	0 25	0.00	0 00	0 00	0.24	0 00	0 00	0.00	0 00	0.00	0 00
GOMang3	0 00	4.41	8.01	0 46	0 00	0 00	0.24	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	0.00
NAV10	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0 00
NAV32c	0.59	0.00	0 00	5 28	50.25	31.17	1 71	8 10	0 00	25.79	74.28	0.00	0 00	0 00	0 84	0.00
NAV42	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00
NAV50	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00

Spp	MacIs20	MacIs21	MacIs22	MacIs23	MacIs24	MacIs25	MacIs26	MacIs27	MacIs28	MacIs29	MacIs30	MacIs31	MacIs32	MacIs33	MacIs34	MacIs35
NAV50c	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00
NAV54b	0.00	0 00	0.00	0.92	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0.85	0 00	0.63	0 48
NAV55	0 29	0.00	0 32	1.61	0 00	0.00	0.73	0.21	0 00	0.00	0.22	0.24	0.00	0.00	1.46	2.88
NAV57	0 00	0.00	0 00	2.98	0 00	0.00	3.91	0.00	0 00	0.00	0.00	0 00	4 51	0.00	2 51	2.40
NAV57a	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0.00
NAV60	0.00	0 00	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0 00
NAV61	0.00	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0.00	0.00
NAV61a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00
NAV61b	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0 00
NAV63	0.00	0 00	0 00	15 14	5 25	11 47	1.22	52.67	0.00	3.16	1 77	0.00	6 48	0.42	1.04	0 00
NAV65	0 00	0 00	0 00	0.69	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0.48	2 54	0 00	0.00	0.00
NAV66	0.00	0 00	0.00	0.00	0.75	0 00	3.67	0 64	0.00	0.00	0 00	1.45	1.13	0.00	0.21	0 48
NAV67	0.00	0.00	0.00	0.00	0.75	0 00	0.00	0 00	0.00	0 00	0.00	0 00	1.41	0.00	0 00	0 00
NAVcon	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0 00	0.00	0 00	0.00	0.00	0 00	0 00
NAVgot	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0 00
NAVmut	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0 00
NAVniv	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0 00	0.00	0 00
NAVper2	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00
NAVryn5	0 00	0.00	0 00	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0 00	0 00
NAVryn6	0 00	0 00	0 64	0.00	0 00	0 00	0.00	0 00	0.23	0.00	0.00	0 00	0.00	0.00	0.00	0 00
NAVryn7	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0 00
NAVvir	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0 00
NIT4b	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0.00	0 00
NIT6	0 00	0.00	0.96	0 00	0 00	0.00	0 00	0 64	0.00	0.00	0.00	0.00	9.58	0 42	0.00	0 00
NIT6a	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0 21	0.24
NIT6c	0.00	0 00	0.00	0.69	0 00	1.50	0 24	0 85	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0 00
NITscal	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0 00
OPE3c	7.35	0.00	0.00	4.36	2 75	3 24	2.93	0 85	0.92	0.00	0.00	0 00	0.00	0 00	0.84	0 00
OPE9	0.00	0.00	3.21	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	2 11	0.63	3 61
OPEbur	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0 00
OPEgue	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0 00	0.00	0.00	0 00	0.00	0 00	0 84	6.01
PIN4	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0.28	0.00	0.00	0.24
PIN4b	0 00	0 00	0.00	0.00	0.00	0 00	0.73	0 21	0 00	0.00	0.00	0 00	0.00	0.00	1.25	0.00
PIN5	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.24	0.00	0 00	0.85	0.00	0.00	0.24
PLAdel	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0.00

Spp	MacIs20	MacIs21	MacIs22	MacIs23	MacIs24	MacIs25	MacIs26	MacIs27	MacIs28	MacIs29	MacIs30	MacIs31	MacIs32	MacIs33	MacIs34	MacIs35
PLAfre3	0.00	0.00	5 45	0.00	0.00	0.00	0 00	0.00	28 34	0.00	0.00	0.00	0.56	0.00	0.00	0.00
PLAfre4	0.00	0 00	0 64	0.00	0 00	0 00	0.00	0.00	6.91	0.00	0.00	0.00	0.00	0 00	0 00	0 24
PLAhau	6.76	0 00	0.64	0.00	0.00	0 00	0.00	0.00	15 90	3.89	0.00	10 84	0.85	0 00	0 42	0 00
PLAhau3	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0 00
PLAhau3b	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0 00
PLAmar	0.00	0 00	0.00	0 00	0 00	0.25	1.96	0.00	0.46	0 00	0 00	0.00	0 00	0.00	0.00	1 20
PLApol2	0.00	0 00	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0.00
PSEsep	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0.00
SYN5	0 00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00
SYNcam	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00
UNK10	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0 00	0.00
UNK100b	0.00	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0 00
UNK117a	0 00	0.00	0 00	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00
UNK117c	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0.00
UNK19c	1 47	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0.00
UNK302a	0 00	0 44	1 28	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00
UNK304	0 00	0 00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0.00
UNK308	0 00	0 00	0 32	3.44	1.25	0 00	3.42	1 49	0.00	0 00	0.00	0 00	0.00	0 21	0 42	0.72
UNK308a	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0 00	3.46	0.24	0.00	0 00	1 97	0 00	0 63	0 00
UNK309	0.00	0 00	0 00	0 00	0.00	0 00	3.42	0.00	0.00	0.00	0.00	0 00	1.13	0.00	0.21	0 00
UNK310	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0 00
UNK37b	1.18	0 00	1 92	6 88	2.00	0 00	11 74	0.00	0 00	0.00	0.00	0.00	2.25	0.00	1.67	7 45
UNK57	0.00	0.00	0.00	1 61	0.50	3.24	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00
UNK57b	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	4 23	0.21	0 00	0.00
UNK70a	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
UNK87c	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00
UNK87d	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0.46	0 00	0 00	0.00	5.35	0 00	0.00	0.00

Spp	MacIs36	MacIs37	MacIs38	MacIs39	MacIs40	MacIs41	MacIs42	MacIs43	MacIs44	MacIs45	MacIs46	MacIs47	MacIs48	MacIs49	MacIs50	MacIs51
ACH1	0.00	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0 00
ACH15	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0 00	0.00	0 00	0.00	0.00	0.00
ACH25	0 00	0 00	0 00	3 82	0.24	0 26	0.35	0 00	0.00	3.27	0 25	0 00	0.00	0 00	0.00	0 00
ACH25a	0 00	0 00	0 00	0 00	0 00	0.00	0.71	0.00	0.00	0 00	6.30	0 00	0.00	0.00	0 00	0 70
ACH25c	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0 00	0.00	0 40	0.00
ACH26	0.00	0.00	0.00	40 33	4.85	5.14	0 00	0.00	0 00	6.53	26 70	81.25	4.44	6 70	0.00	1 63
ACH3	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0 00	0.00	0 00	0.00	0 00
ACH32	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	4.53	0 00	0 25	0 50	0.00	0 00
ACH33	0 00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0.00	2.27	0.00	0 00	0.00	0 00	0.00
ACH38	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0.00
ACH38a	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0.00
ACH41	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0 00	0.00	0 00	0.00	0 00	0.00
ACH42	0.00	0 00	0.00	0 00	0 00	0.00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0.00	0 00	0.00
ACH4c	0 00	0 00	5.50	0 00	1 70	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0 00	0.00	0 00
ACH5	14.36	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0.00
ACHbre	0 00	0 00	0.24	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0 00	0 00
ACHpse3	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0 00
ACHpse4	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0.00	0 00	0.00
ACHpse5	0.00	0.00	0 00	0.00	0 00	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0 00
ACHsub	0 00	0 00	0 00	1 43	0.00	0 26	0 00	0 00	0 21	2 26	0.76	0.46	0.00	0.00	0.00	0 00
ACHsub1	0.00	0 00	0 00	0.00	0.00	0.00	1.06	0 00	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0.00
ACHsub2	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0.00
AMP11c	0 00	0.00	0.00	0.00	0 00	2 57	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0 40	0 00
AMP18a	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00
AMP22	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0 00
AMP23	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0 00
AMP4	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0 00
AMPcof	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00
AMPven	0 00	5 52	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0 00
AULgra	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0.00	0 00	0 00	0 00
AULita	0 00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0.00
AULval	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Spp	MacIs36	MacIs37	MacIs38	MacIs39	MacIs40	MacIs41	MacIs42	MacIs43	MacIs44	MacIs45	MacIs46	MacIs47	MacIs48	MacIs49	MacIs50	MacIs51
CEN15	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0 00	0 00	0.00	0.00	2 48	0 00	0 00
CEN16	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0 00
CEN16a	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0 00
CEN17	0.00	0 00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0 00
CEN5	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.25	0.00	0 00
COC13	0.00	0 00	0 00	0.48	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0.00
COC13a	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0.00	0 00	0.00	0 00
COC15	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0.00
COC15a	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0 00
COC8	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.25	1 24	0.00	0.00
COC8a	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0 00
COCdis	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.01	0 00	0.00	0 00	0 00	0 00
COCpla	7.30	0 00	0 00	0.24	0.73	1 54	0.00	0 00	0.00	0.25	1.01	0.00	0.00	0 00	0 00	0.00
COCscu	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0 00	1.74	0 00	0 00
CYCmen	0 00	0 00	0 00	9 07	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0 00
CYCstr	1.46	0 19	0.00	0 00	0 00	0 00	6.74	0 00	0.21	1.01	0 00	0 00	0.00	0.00	0 00	0.00
CYMasp3	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0 00
DIP11	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0.00	0 00
EUNnae	0 00	0 76	0 72	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0.00
FRA12	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0.00
FRA3	0 00	0 00	0 00	0.24	0.00	0 00	0.00	0 00	0.00	2 51	1 26	0.00	0 25	3 47	0.00	0 00
FRA3a	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 25	0.00	0.00	0.00	0.00	0.00	0 00
FRA7	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	1 26	0.00	0.00	0 00	0 00	0 00
FRA8	71.29	92.00	80.14	12 41	45.63	11 05	48 58	98.75	97.49	45.23	17 13	9 49	84.20	53 35	80.36	47 21
FRA8a	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0.63	0.00	0 00	0.00	0.00	0.00	15 83	48.37
FRAcap2	0.00	0 00	0.00	0.00	0.00	0.00	0.35	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0 00
FRUrho	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0 00
GOMang	0.00	0.00	0.00	0.95	0.49	0.26	0.00	0.00	0.00	0 00	2 02	0.00	0 00	0.99	0.20	0 00
GOMang1	0.00	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	5 78	0.00	0 00	0 00	0.00	0.00	0 00
GOMang2	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00
GOMang3	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00
NAV10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00
NAV32c	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0.00
NAV42	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00
NAV50	0.00	0.00	0.00	1.91	0.49	0.77	1.77	0.00	0.21	1.51	0.00	0 00	0.00	0 00	0 00	0 00

Spp	MacIs36	MacIs37	MacIs38	MacIs39	MacIs40	MacIs41	MacIs42	MacIs43	MacIs44	MacIs45	MacIs46	MacIs47	MacIs48	MacIs49	MacIs50	MacIs51
NAV50c	0.00	0 00	0.00	0 00	0 00	0 00	3.55	0 00	0 00	0 00	0 00	0.23	0.49	0 99	0 00	0 00
NAV54b	0.00	0 00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0.00	0.00
NAV55	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 99	0.00	0.23
NAV57	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00
NAV57a	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00
NAV60	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0 00
NAV61	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0 25	0 00	0 00	0.00
NAV61a	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0 00
NAV61b	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0 00	0 00
NAV63	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00
NAV65	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0 00
NAV66	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0 00
NAV67	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00
NAVcon	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0 00
NAVgot	0 00	0.00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0 00
NAVmut	0.00	0 00	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0.00	0.00
NAVniv	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00
NAVper2	0.00	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NAVryn5	0.00	0 00	0 00	0.00	2.43	0 00	0.00	0 00	0.00	0.00	0.00	0 00	1.23	0 00	0 20	0.23
NAVryn6	0.00	0 00	0 00	0 00	0 00	0.00	0.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NAVryn7	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	0.00	0 00
NAVvir	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0.00
NIT4b	0 00	0.00	0.00	0 00	1 21	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0.00
NIT6	0 00	0.00	0.00	0 00	0.24	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0 25	0 00	0 00
NIT6a	0 00	0 00	0.00	0 00	0 49	0.00	0 00	0 00	0 00	0 50	0 50	0.00	0 00	0 00	0 20	0 00
NIT6c	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00
NITscal	0 00	0 00	0 00	0 00	1.46	0.26	0 00	0 00	0 00	0.25	0.00	0 00	0.00	0 00	0 00	0.00
OPE3c	0 00	0.00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0 00	0.00
OPE9	0.00	0.00	0.00	0 00	0.00	0 00	30 14	0.00	1.04	3.02	3.27	0.00	0.25	0 74	0 20	0 23
OPEbur	0.00	0 00	5.98	0.00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0 00
OPEgue	0 00	0.00	5.74	0 00	0 00	1 80	0.71	0.00	0.00	3.02	0.00	0.00	0.00	0.00	0.00	0 00
PIN4	0.00	0.00	1.20	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0 00
PIN4b	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0 00
PIN5	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0.00
PLAdel	0.00	0 00	0.00	0 00	4.85	0.77	0 00	0 00	0 00	0 25	0 00	0 00	0 00	0.00	0 00	0.00

Spp	MacIs36	MacIs37	MacIs38	MacIs39	MacIs40	MacIs41	MacIs42	MacIs43	MacIs44	MacIs45	MacIs46	MacIs47	MacIs48	MacIs49	MacIs50	MacIs51
PLAfre3	1.22	0 57	0 48	7.16	6.55	0.51	0 71	1.00	0 21	10.55	14 86	7 64	6 67	19 11	0.60	0 00
PLAfre4	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0 50	0.00	0 00
PLAhau	0 00	0 00	0 00	2 15	23.30	70 44	0 71	0.25	0.00	4 52	8 06	0.00	0 00	0.50	0 00	0.00
PLAhau3	0.00	0 00	0.00	0 00	0 00	0.00	0 00	0.00	0 00	0 00	5.54	0 69	0.74	2.23	1.40	0 00
PLAhau3b	0.00	0 00	0.00	0.00	0.00	0.00	0 00	0.00	0.00	7.79	0 00	0 00	0 00	0.00	0.00	0 00
PLAmar	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0.00
PLApol2	0.24	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0.00
PSEsep	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0.00
SYN5	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0 00	0.00
SYNcam	0.00	0 00	0.00	2.86	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0 00
UNK10	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00
UNK100b	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0 00
UNK117a	1 95	0 00	0 00	2.15	3 16	0 00	0 00	0.00	0 00	0.00	0 00	0 00	0 74	0 00	0 00	0 47
UNK117c	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0 00	0 00
UNK19c	0.00	0 00	0.00	0.24	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0 00
UNK302a	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0 00
UNK304	0 00	0.00	0 00	0 00	0.00	0.00	1 06	0 00	0 00	0 00	1 26	0.00	0 00	0.00	0 00	0.00
UNK308	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0.00	0 00
UNK308a	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0.00
UNK309	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0.00
UNK310	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00
UNK37b	1 46	0 38	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0.00
UNK57	0 00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00
UNK57b	0.00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0.00	0 00	0.00
UNK70a	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0 00	0.00
UNK87c	0 00	0 00	0 00	13 37	0 00	2 06	0 00	0 00	0 00	0.00	0.00	0 23	0.00	0 00	0.00	0 00
UNK87d	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	0.00

Spp	MacIs52	MacIs53	MacIs54	MacIs55	MacIs56	MacIs57	MacIs58	MacIs59	MacIs60	Maximum	Mean
ACH1	0.00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	1.17	0.03
ACH15	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	4.66	0.09
ACH25	0.23	0.45	1.22	0 00	1.56	0.00	1 92	0.00	5 25	28.80	0 88
ACH25a	0 00	0 00	7 80	0.00	0 00	0 00	0 00	0 00	1.00	7 80	0.32
ACH25c	0 00	0.00	0 00	0 00	0 00	0.00	1 92	0.00	0.00	1 92	0 04
ACH26	4.29	18 10	8 29	0 00	11.70	5 88	0.00	63 48	30 50	81 25	5 52
ACH3	0.00	0.00	0 00	0 00	0 00	0 00	0.00	0.00	0.00	3.72	0.09
ACH32	0.23	0 68	0 73	2.59	4.09	0 98	4.81	0.00	0.00	4 81	0.41
ACH33	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	2 27	0 04
ACH38	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	8.50	0 15
ACH38a	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	7 25	0.13
ACH41	0 00	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0 00	8 73	0 35
ACH42	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0 00	2 65	0 11
ACH4c	0.00	0 00	0.00	0 00	0 00	0.00	0 00	0.00	0 00	5 50	0 13
ACH5	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	14.36	0 25
ACHbre	0 00	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	1 00	0 02
ACHpse3	0 00	0.00	0 00	0.00	0.00	0 00	0.00	0 00	0 00	1 90	0.14
ACHpse4	0 00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	9 71	0.18
ACHpse5	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0 00	2 67	0 05
ACHsub	0.23	0 00	0.00	0.00	0 00	0.00	0.00	0 98	0 25	62.50	3.78
ACHsub1	0.00	0 00	0 00	0.00	0 00	0.00	9.62	0 00	0 00	9.62	0 38
ACHsub2	0 00	0.00	0.00	0 00	0.00	0 00	0 00	0.00	0 00	95 06	8.19
AMP11c	0.23	0 00	0 98	0 00	0 00	0.00	0 00	0 00	0.00	2.57	0 14
AMP18a	0.00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	6.98	0.52
AMP22	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	1 44	0 08
AMP23	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	13.72	0.30
AMP4	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	3 40	0.06
AMPcof	0 00	0 00	0.00	0 00	0 00	0 00	0.00	0 00	0.00	1 54	0.04
AMPven	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0 00	0 00	5.52	0 10
AULgra	0 00	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0 00	2 33	0.04
AULita	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	6.29	0 11
AULval	0 00	0 00	0.00	0 00	0.00	0 00	0 00	0.00	0 00	5 13	0.09

Spp	MacIs52	MacIs53	MacIs54	MacIs55	MacIs56	MacIs57	MacIs58	MacIs59	MacIs60	Maximum	Mean
CEN15	0 00	0 00	0 00	0.00	0.39	0 00	52 88	0 00	0 50	52 88	0 97
CEN16	0 00	0 00	0.00	0.00	0.00	0 00	0 00	6 37	0 00	50.00	1 14
CEN16a	0.00	0.00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	75 18	3.27
CEN17	0.00	0.00	0.00	0 00	0.00	0 00	0 00	0 00	0.00	42 65	0.86
CEN5	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	1 25	1.25	0 03
COC13	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	2 50	0 08
COC13a	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	13.45	1 10
COC15	0.00	0 00	0.00	0 00	0 00	0.00	0 00	0.00	0 25	1.10	0 04
COC15a	0 00	0 00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	5 45	0.11
COC8	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	49.76	2.36
COC8a	0 00	0 00	0.00	0 00	0.00	0 00	0.00	0 00	0.00	5 51	0 18
COCdis	0 00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	1.01	0.02
COCpla	0 00	0.00	0.00	0 00	0 00	0 00	1 92	1 23	0.00	7 46	0.37
COCscu	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	1.74	0.03
CYCmen	0 00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	9 07	0.16
CYCstr	0 00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	0.00	6 74	0 19
CYMasp3	0.00	0.00	0.00	0 00	0 00	0.00	0 00	0.00	0 00	5 50	0 10
DIP11	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	1.92	0 06
EUNnae	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0 00	1 25	0.05
FRA12	0.00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0.00	2 24	0 04
FRA3	0 00	0 00	0.00	0 00	0 00	0 00	0 96	0.00	0 00	6 97	0.40
FRA3a	0 00	0.00	0.00	0 00	0.00	0 00	0 00	0.00	0.00	2 88	0.15
FRA7	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	1 26	0 02
FRA8	74.72	56 11	41.71	94.30	5 26	9.80	0 96	0 00	37 25	98.75	30.52
FRA8a	13 54	17 42	6.34	2.42	0.00	0.00	0 00	0 00	0 00	48 37	3 00
FRAcap2	0.00	0 00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	79.45	1 44
FRUrho	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0.00	3 25	0 09
GOMang	0 23	2 49	6 10	0.00	1.95	2 94	0.96	0 00	0.25	6 10	0 46
GOMang1	0 00	0 00	1.22	0.00	0 19	0.00	0.00	0.00	0 00	5 78	0 12
GOMang2	0 00	0.00	0 00	0.00	0 00	0.00	0.00	0 00	0.00	8 01	0 22
GOMang3	0 00	0.68	0 00	0 00	0.00	0 00	0 00	0 00	0 00	8 01	0 30
NAV10	0.00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0 00	1.40	0 03
NAV32c	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	74 28	3 57
NAV42	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	4.00	0 11
NAV50	0.23	0.00	0.73	0.00	0.00	0 00	0 00	0.00	0 00	1 91	0 15

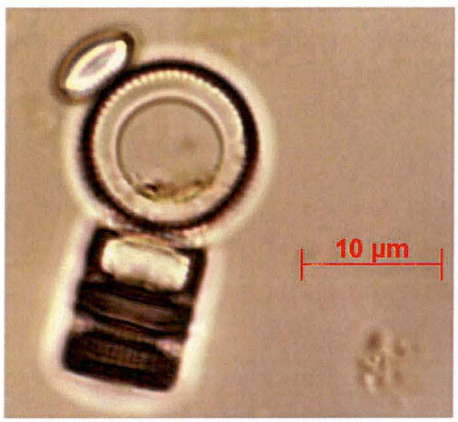
Spp	MacIs52	MacIs53	MacIs54	MacIs55	MacIs56	MacIs57	MacIs58	MacIs59	MacIs60	Maximum	Mean
NAV50c	0 00	0.45	1 71	0 00	0 00	0.00	0 00	0 00	0.00	3 55	0 14
NAV54b	0.00	0 00	0.00	0 00	0.00	0.00	0.00	0.00	0 00	1 14	0.08
NAV55	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0 00	0 00	2.94	0.27
NAV57	0.00	0.00	0 49	0 00	0.00	0 00	0.00	0.00	0 00	4.51	0.42
NAV57a	0 00	0 00	0.00	0 00	0.00	0 00	0 00	0 00	0 00	1 94	0.03
NAV60	0 00	0 00	1.95	0.00	0.00	0.00	0 00	0 00	0 00	1.95	0.03
NAV61	0 00	0 00	1 71	0.00	0 39	0 00	0.00	1 72	0.00	1 72	0.07
NAV61a	3 39	0 90	0 24	0.00	0.00	0 00	0.00	9.56	0.50	9.56	0.26
NAV61b	0 00	0.00	0 00	0.00	0.00	0 00	0 00	0.74	2 25	2 25	0.05
NAV63	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0.00	0 00	52 67	1.78
NAV65	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0.00	2 54	0.07
NAV66	0.00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	3.67	0 14
NAV67	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	1.41	0.04
NAVcon	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	3.00	0.05
NAVgot	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	5.75	0 12
NAVmut	0.00	0.00	0.00	0.00	0 00	0.00	0 00	0 00	0 00	1 50	0 05
NAVniv	0 00	0.00	0.00	0 00	0.00	0 00	0.00	0 00	0 00	2 00	0 03
NAVper2	0 00	0.00	0.00	0 00	0 00	2 94	1 92	0 00	0 00	2 94	0 08
NAVryn5	0 00	0.00	1.22	0 00	0 00	0.00	0 00	0 00	0 00	2 43	0 12
NAVryn6	0 00	0 00	0 00	0 00	0 00	0 00	1 92	0.00	1 50	1 92	0.08
NAVryn7	0.00	0.00	0.00	0 00	0 00	1.96	0.00	0 00	0 00	1 96	0.03
NAVvir	0.00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0.00	1.25	0 02
NIT4b	0 23	0 00	0 00	0 00	0 00	0 00	0 00	0.00	0.00	1 21	0.03
NIT6	0 00	0 00	0.00	0 00	1 75	3.92	0.00	0 00	0 25	9.58	0.34
NIT6a	0.00	0 00	0.00	0.00	3 51	0 00	0 00	0.00	0 00	3 51	0 15
NIT6c	0.00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0.00	1 50	0 09
NITscal	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0.00	1 46	0.04
OPE3c	0 00	0.00	0 00	0.00	0.00	0 00	0.00	0.00	0 00	9.93	0 65
OPE9	0.00	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	30.14	0 95
OPEbur	0 00	0.00	0.00	0 00	0 00	0 00	0 00	0 00	0.00	5 98	0 10
OPEgue	0 00	0.00	0.00	0 00	0.00	0 00	0.00	0 00	0.00	12 82	0 55
PIN4	0 00	0.00	0.00	0 00	0 00	0 00	0.00	0 00	0 00	1 50	0 10
PIN4b	0.00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0.00	1 25	0 04
PIN5	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0 00	0.00	1.29	0 07
PLAdel	0 00	0 00	0.00	0 00	0.00	0.00	0.00	0 00	0.00	4 85	0 10

Spp	MacIs52	MacIs53	MacIs54	MacIs55	MacIs56	MacIs57	MacIs58	MacIs59	MacIs60	Maximum	Mean
PLAfre3	0 45	2.26	15 37	0 35	3 12	0.98	2.88	9.31	17 75	34.47	4.28
PLAfre4	0.00	0 00	0.00	0 00	0 00	0 00	0.00	0.00	0.25	6.91	0 15
PLAhau	0 00	0.00	0.00	0 00	61.79	68 63	16.35	0.98	0.00	70.44	6.23
PLAhau3	0.68	0.00	0.24	0 00	2 34	0.00	0.00	4.66	0.00	5.54	0.33
PLAhau3b	0 00	0.00	0.00	0 00	0.00	0.00	0 00	0.00	0 00	7 79	0 13
PLAmar	0.00	0.00	0 00	0.00	0 00	0.00	0 00	0.00	0 00	1 96	0 09
PLApol2	0 00	0.00	0.00	0 00	0 00	0.00	0.00	0 00	0 00	1 75	0.04
PSEsep	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	4 00	0.12
SYN5	0 00	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	47.00	1 13
SYNcam	0 00	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0 00	2 86	0.05
UNK10	0.00	0.00	0 00	0.00	0.00	0 00	0 00	0.00	0.00	3.00	0 05
UNK100b	0 00	0 00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	4 66	0 09
UNK117a	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	0 00	3 16	0 17
UNK117c	0 00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	4 50	0.08
UNK19c	0 00	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	1.47	0.03
UNK302a	0 00	0 00	0 00	0.00	0.00	0 00	0 00	0 00	0 00	1 28	0.03
UNK304	0 00	0 00	0 00	0.00	0 00	0 00	0 00	0 00	0 00	1 26	0.04
UNK308	0 00	0 00	0.00	0.00	0.00	0 00	0.00	0 00	0.50	3.44	0.21
UNK308a	0.00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0.00	3 46	0 11
UNK309	0.00	0 00	0 00	0.00	0 00	0 00	0.00	0 00	0.00	3 42	0 12
UNK310	0 00	0 00	0 00	0.00	0.00	0 00	0.00	0 00	0 00	64 72	1.12
UNK37b	0.00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	11 74	0.72
UNK57	0.00	0 00	0 00	0.00	0.00	0.00	0 00	0 00	0 00	3 24	0.11
UNK57b	0 00	0.00	0.00	0.00	0.00	0.00	0 00	0 00	0 00	56 25	1.35
UNK70a	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0 00	1.50	0 03
UNK87c	0 00	0.00	0.00	0 00	0.58	1 96	0.00	0 00	0 00	13.37	0.48
UNK87d	0.00	0 00	0 00	0 00	0.00	0 00	0.00	0.00	0 00	5.35	0 10

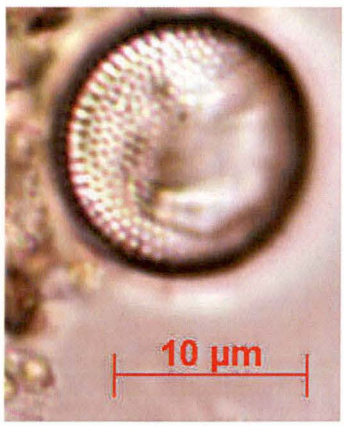
Appendix 6: Macquarie Island diatom species images

PLATE 1

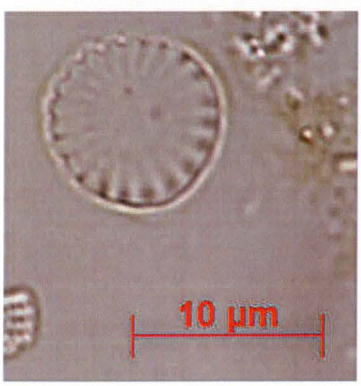
1



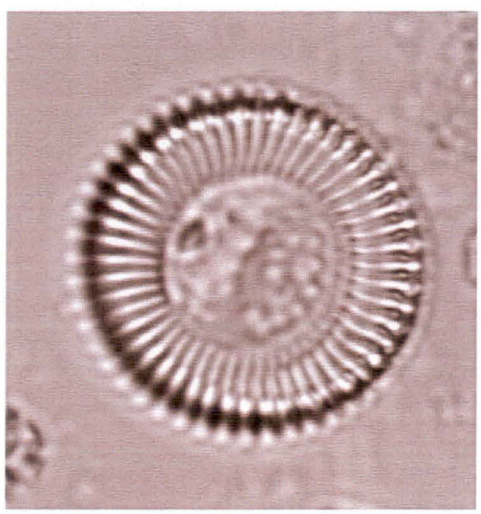
2



3



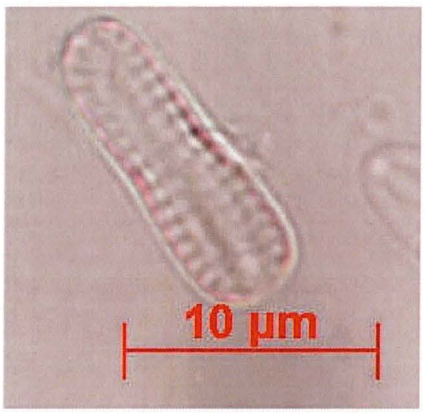
4



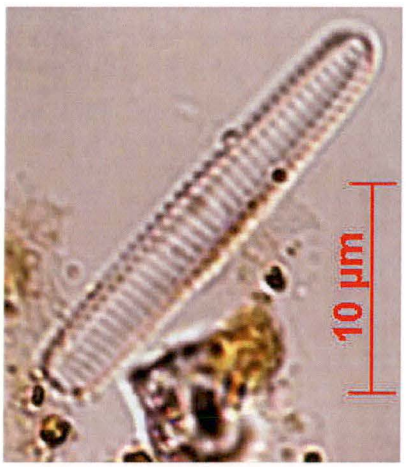
1. *Aulacoseira distans* (Ehrenberg) Simonsen
2. *Aulacoseira distans* var. 1
3. *Cyclotella meneghiniana* Kützing
4. *Cyclotella striata* (Kützing) Grunow

PLATE 2

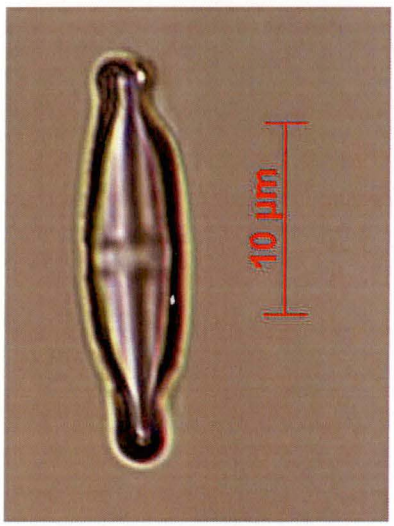
1



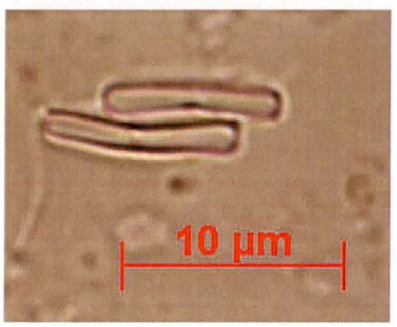
2



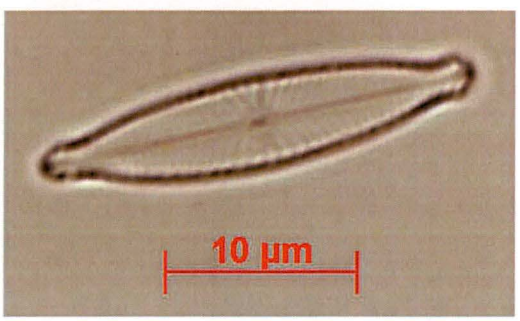
3



4



5

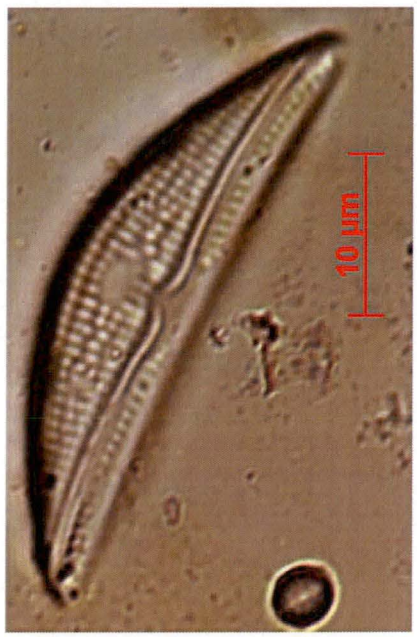


1-2. *Achnanthes brevipes* C. Agardh
3. *Achnanthidium minutissimum* (Kützing) Czarnecki
4. *Achnanthes* cf. *subexigua* Hustedt
5. *Adlafia frenotii* Van de Vijver, Ledeganck & Beyens

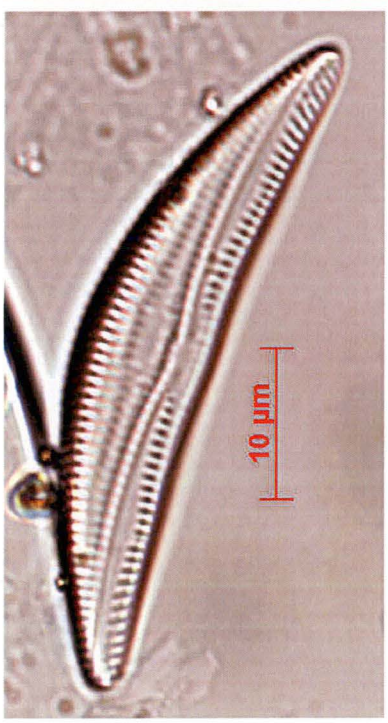
PLATE 3

1

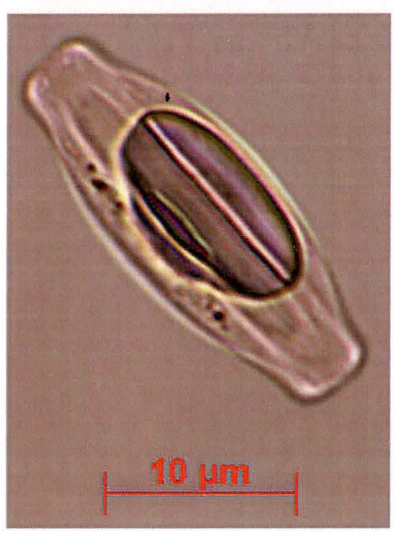
2



3



4



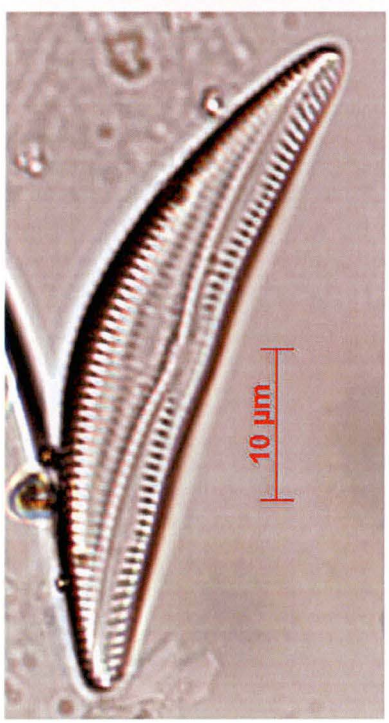
1. *Amphora acutiuscula* Kützing
2. *Amphora copulata* (Kützing) Schoeman & Archibald
3. *Amphora copulata* var. 1
4. *Amphora* sp. 1

PLATE 3

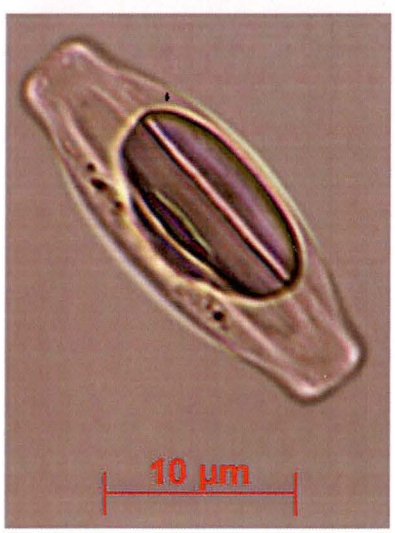
1

2

3



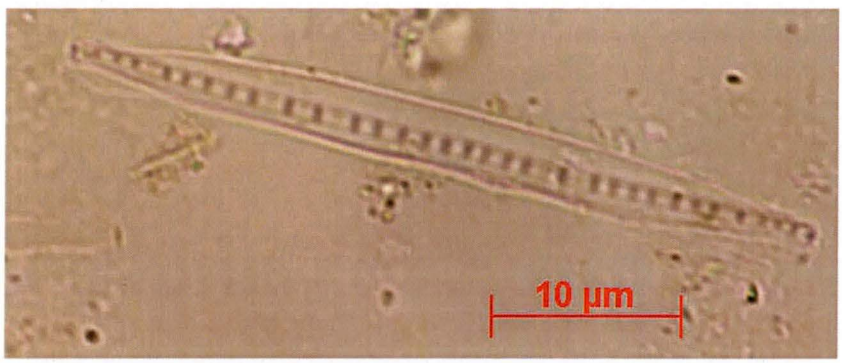
4



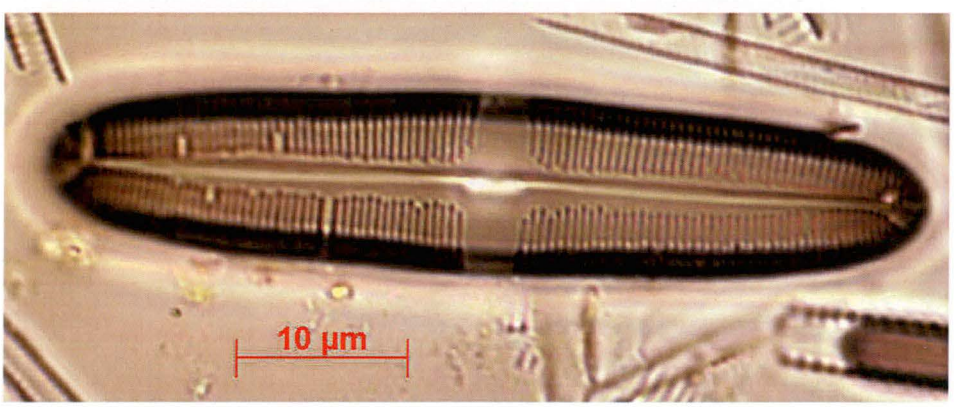
1. *Amphora acutiuscula* Kützing
2. *Amphora copulata* (Kützing) Schoeman & Archibald
3. *Amphora copulata* var. 1
4. *Amphora* sp. 1

PLATE 4

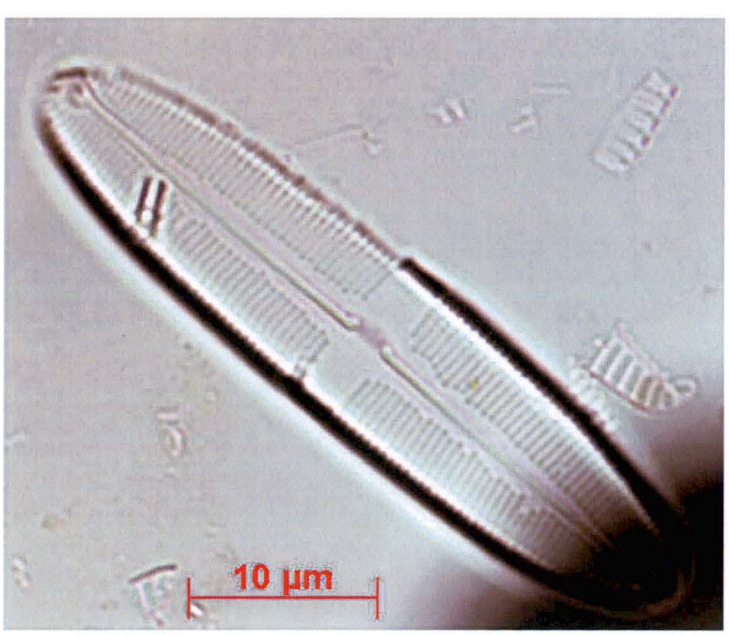
1



2

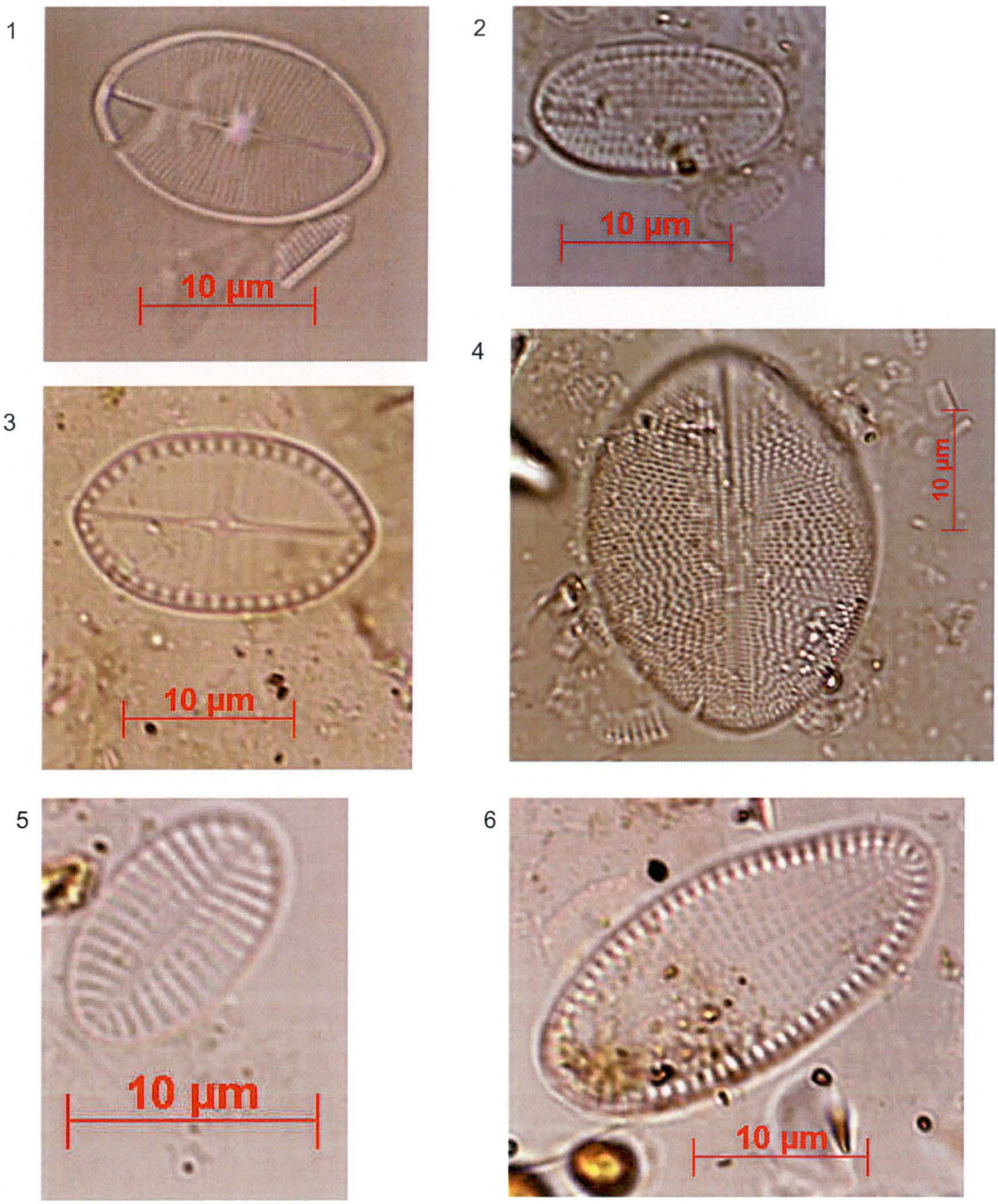


3



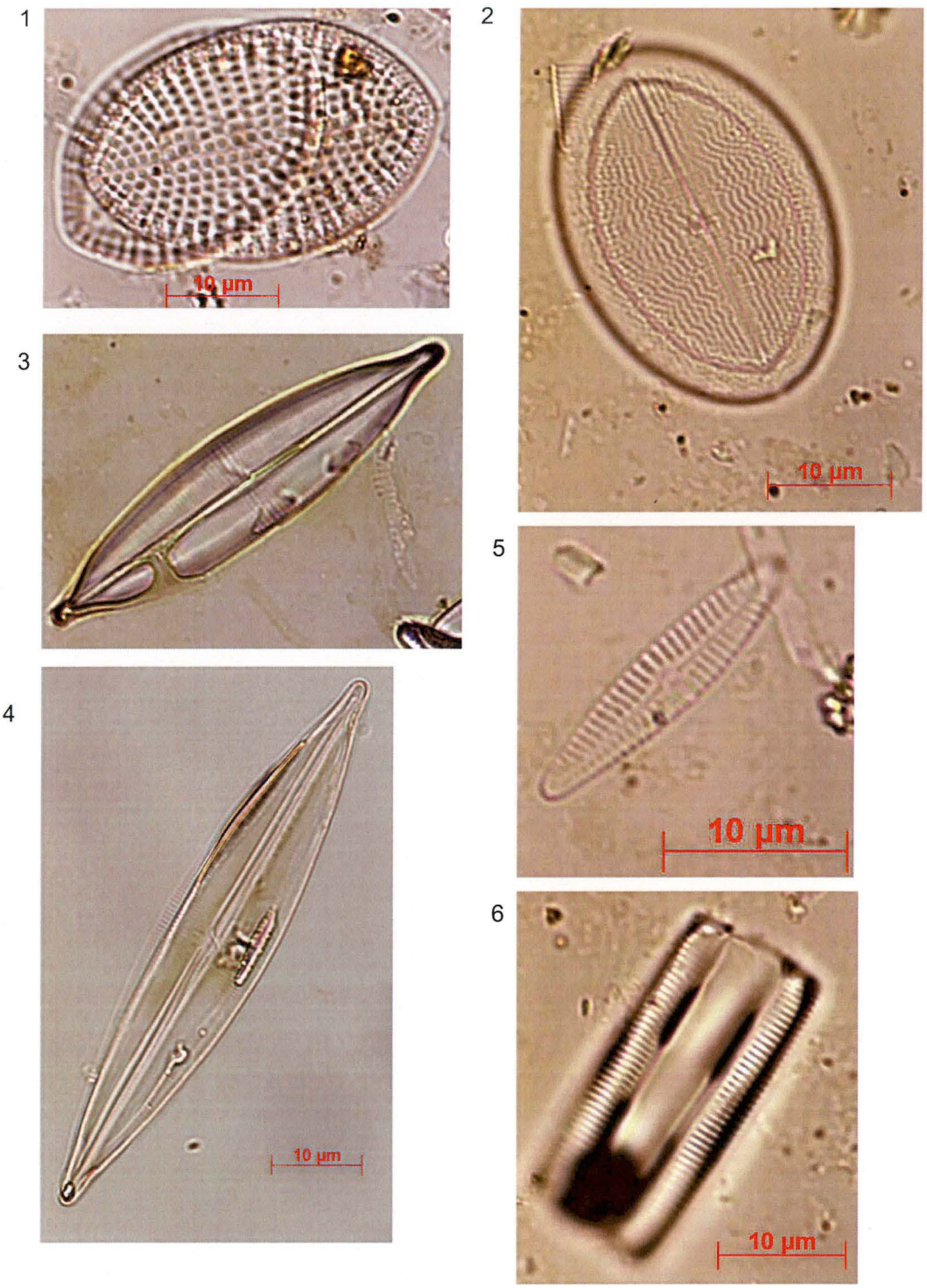
1. *Bacillaria paxillifer* (O.F. Müller) Hendey
2. *Caloneis bacillum* (Grunow) Mereschkowsky
3. *Caloneis bacillum* var. 1

PLATE 5



1. *Cavinula* cf. *pseudoscutiformis* (Hustedt) Mann & Stickle
2. *Cocconeis disculus* (Schumann) Cleve
3. *Cocconeis* cf. *neothumensis* Krammer
4. *Cocconeis pediculus* Kützing
5. *Cocconeis peltoides* Hustedt
6. *Cocconeis* cf. *placentula* Ehrenberg

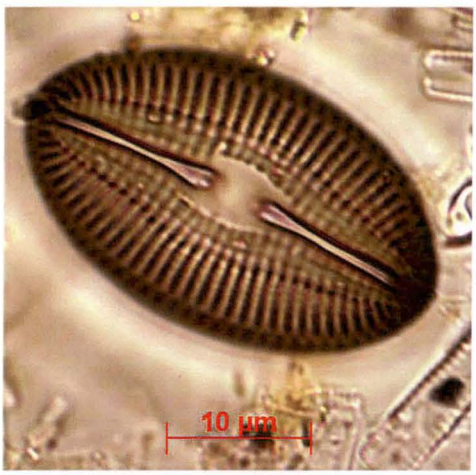
PLATE 6



1. *Cocconeis scutellum* var. *scutellum* Ehrenberg
2. *Cocconeis* sp. 1
3. *Craticula salsuginosa* Van de Vijver & Beyens
4. *Craticula salsuginosa* var. 1
5. *Cymbella* sp. 1
6. *Diatomella* cf. *balfouriana* Greville

PLATE 7

1



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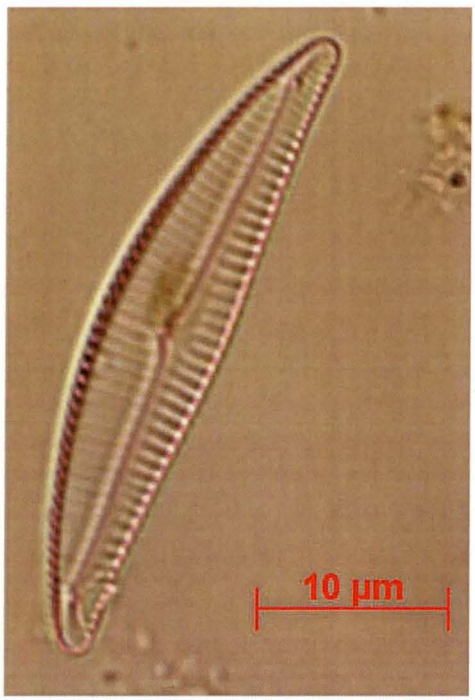

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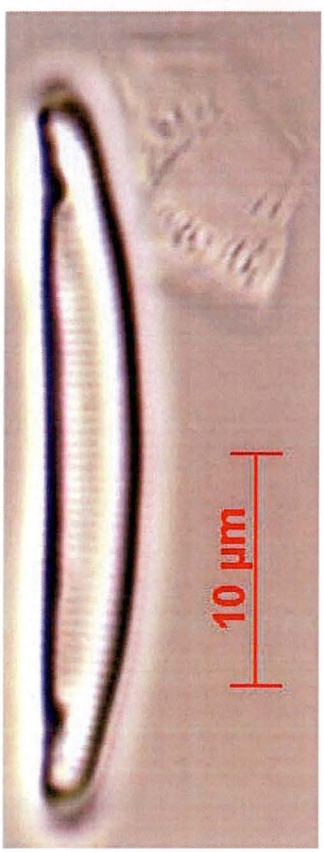


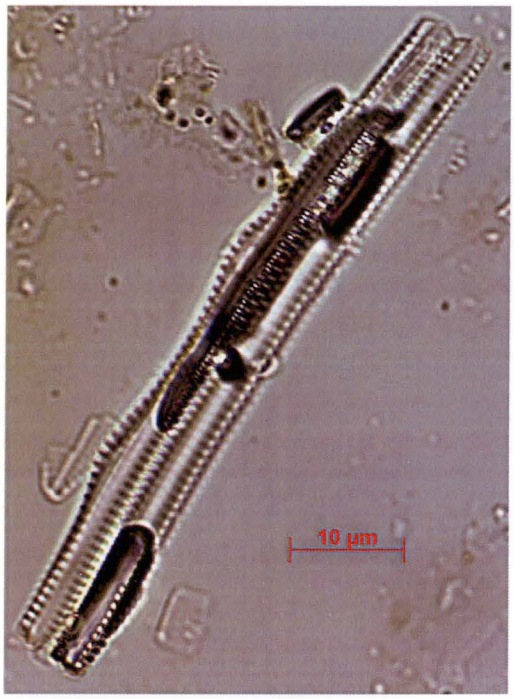
4

1. *Diploneis subovalis* Cleve
2. *Encyonema* sp. 1
3. *Eunotia flexuosa* (Brébisson) Kützing
4. *Fragilaria capucina* Desmazières

PLATE 8

1

2



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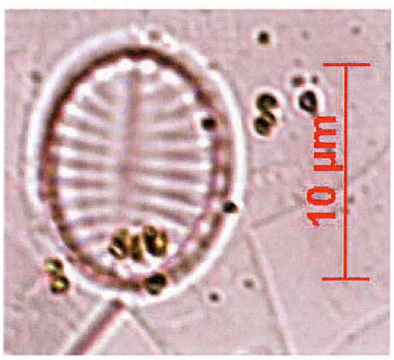

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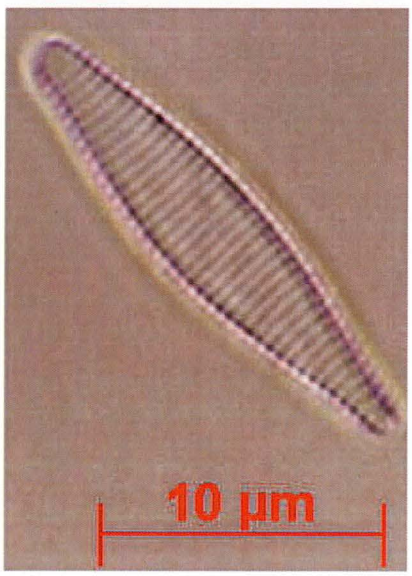
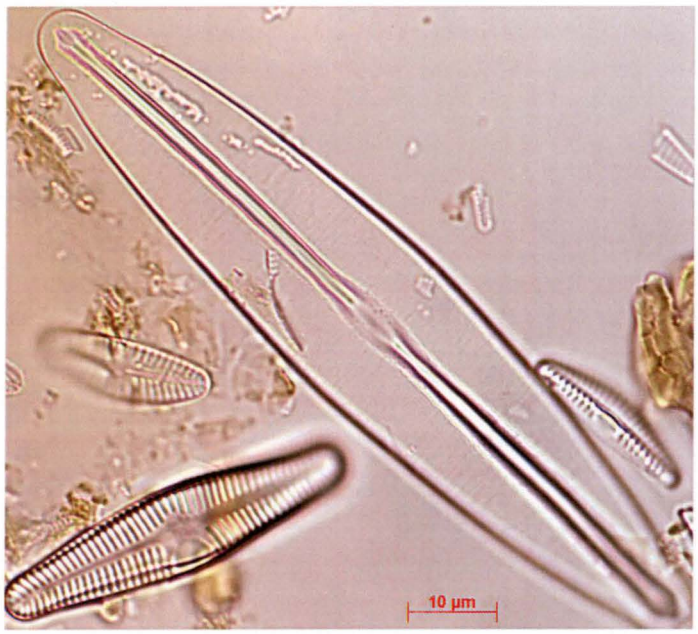


1. *Fragilaria capucina* var. 1
2. *Fragilaria capucina* var. 2
3. *Fragilaria* cf. *sopotensis* Witkowski & Lange-Bertalot
4. *Fragilaria* cf. *virescens* Ralfs

PLATE 9

1



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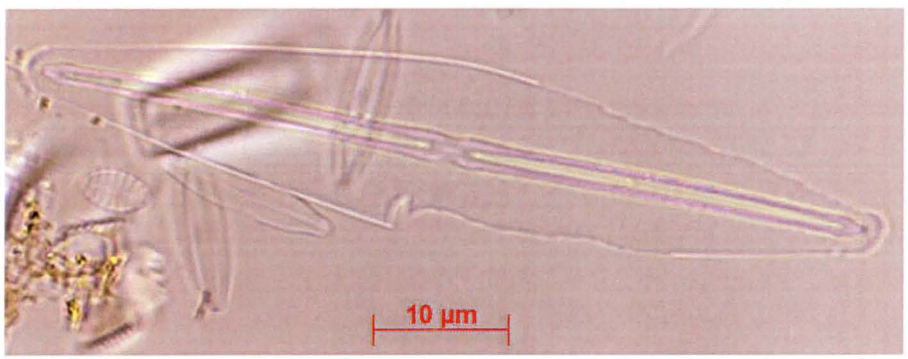
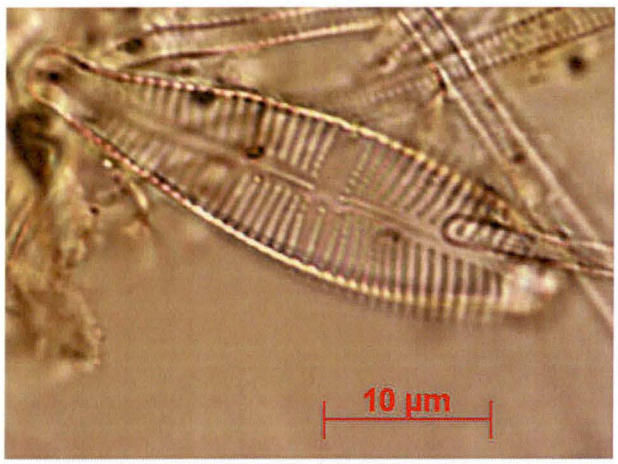


1. *Frustulia* cf. *subantarctica* Van de Vijver & Beyens
2. *Frustulia* cf. *subantarctica* var. 1

PLATE 10

1



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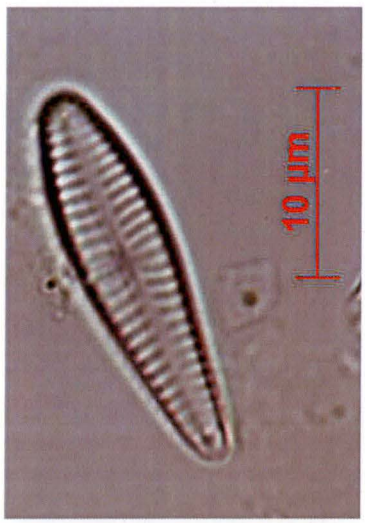

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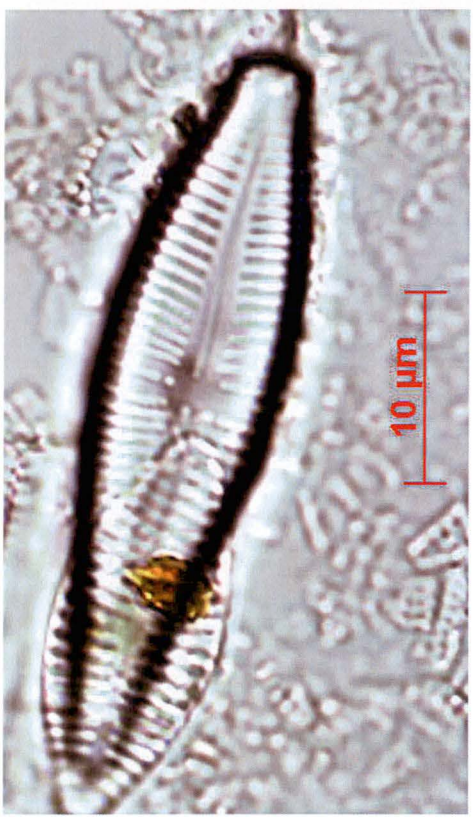

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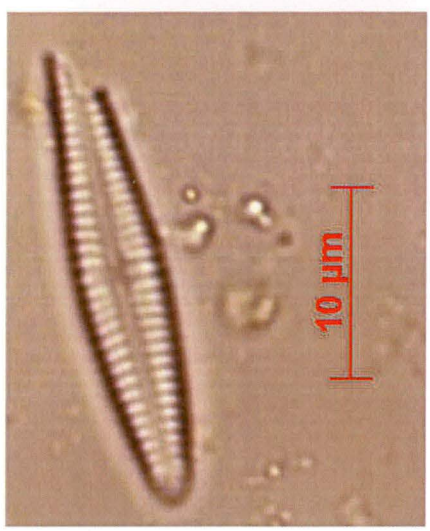
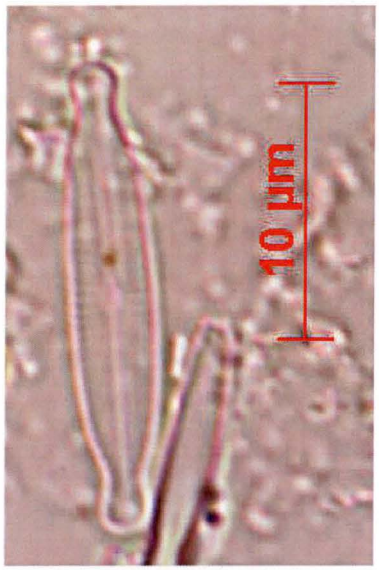


1. *Gomphonema affine* var. *affine* Kützing
2. *Gomphonema angustatum* (Kützing) Rabenhorst
3. *Gomphonema parvulum* (Kützing) Kützing
4. *Gomphonema* sp. 1

PLATE 11

1



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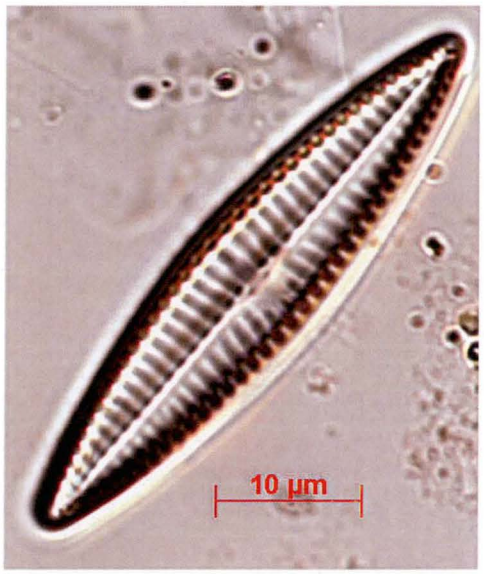
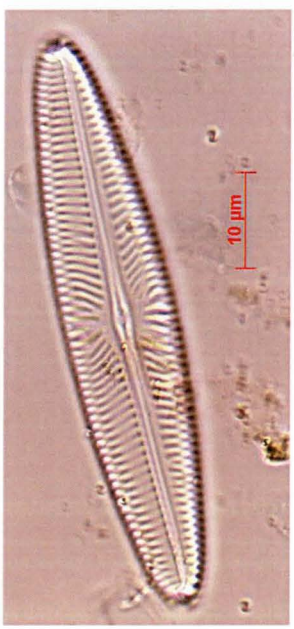


3



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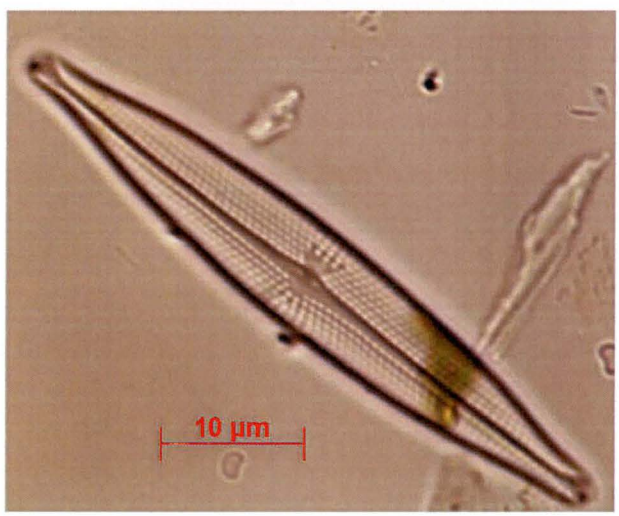
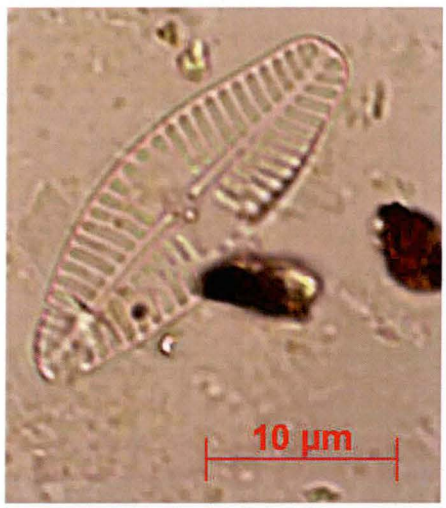


1. *Kobayasiella subantarctica* Van de Vijver & Vanhoutte
2. *Navicula recens* Lange-Bertalot
3. *Navicula viridula* (Kützing) Kützing
4. *Navicula* sp. 1

PLATE 12

1



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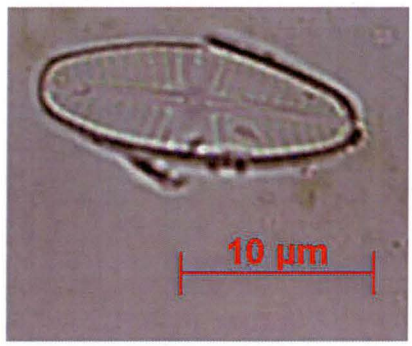

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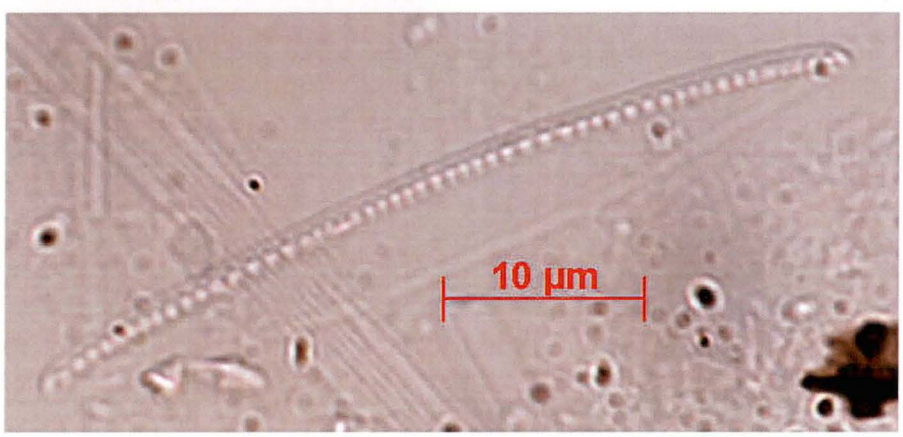

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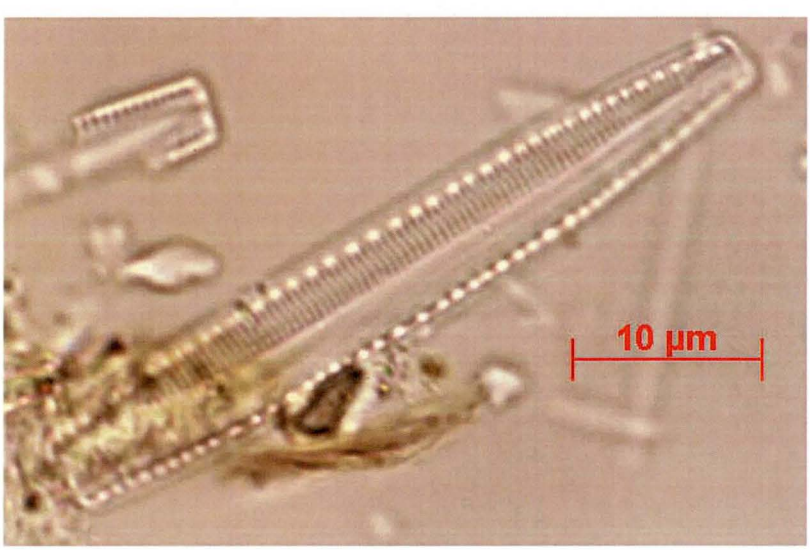
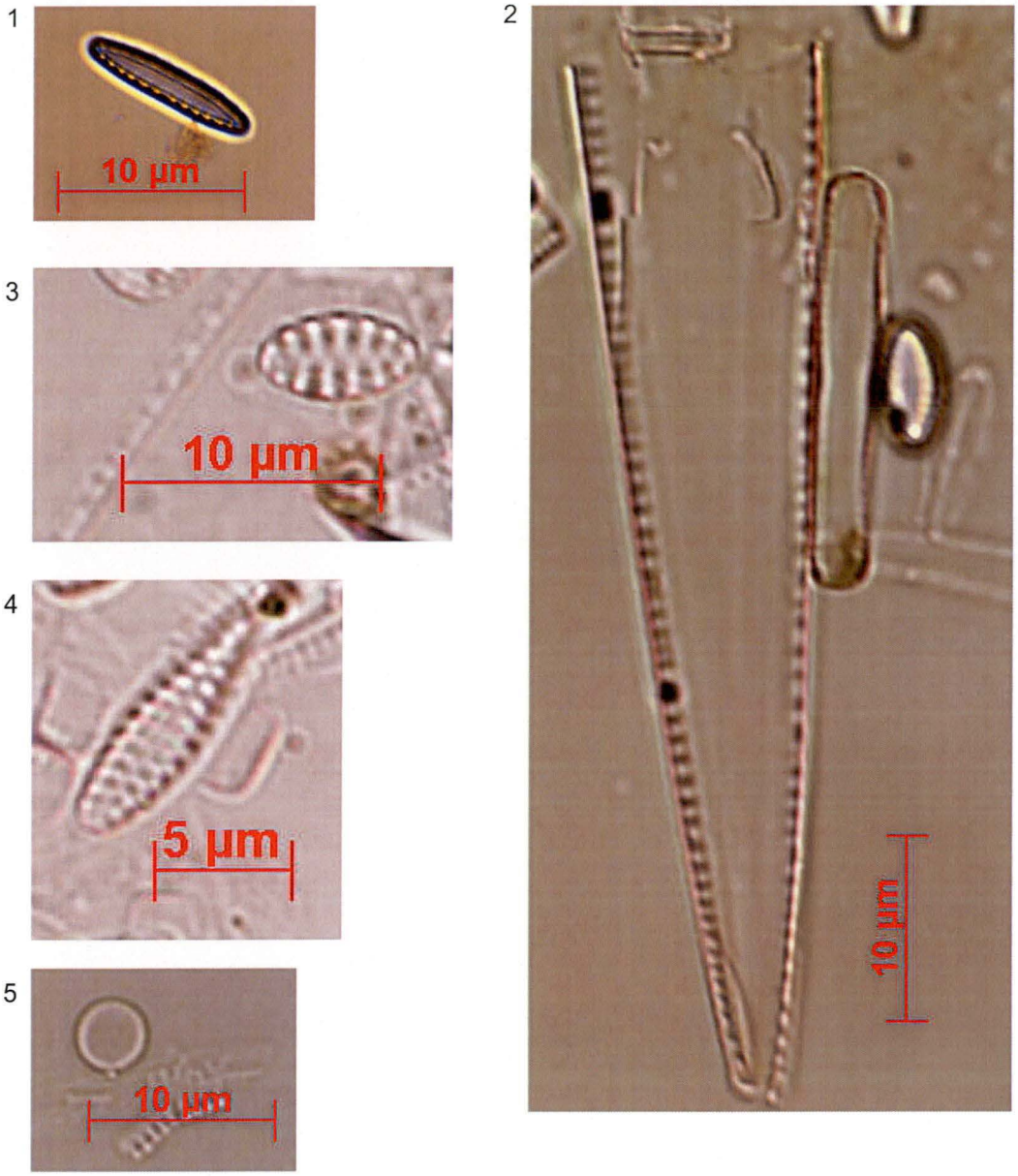


1. *Naviculadicta seminulum* Grunow
2. *Naviculadicta seminulum* var. 1
3. *Nitzschia* cf. *gracilis* Hantzsch
4. *Nitzschia* cf. *hungarica* Grunow

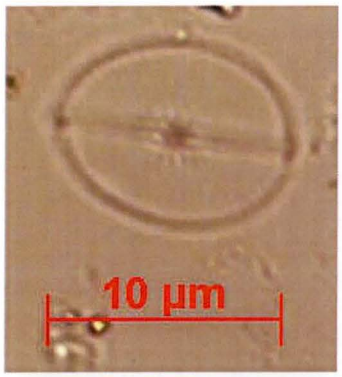
PLATE 13



1. *Nitzschia* cf. *palea* (Kützing) W. Smith
2. *Nitzschia* sp. 1
3. *Opephora* cf. *guenter-grassii* (Witkowski & Lange-Bertalot) Sabbe & Vyverman
4. *Opephora krumbeinii* Witkowski, Witak & Stachura
5. *Opephora* cf. *pacifica* (Grunow) Petit

PLATE 14

1



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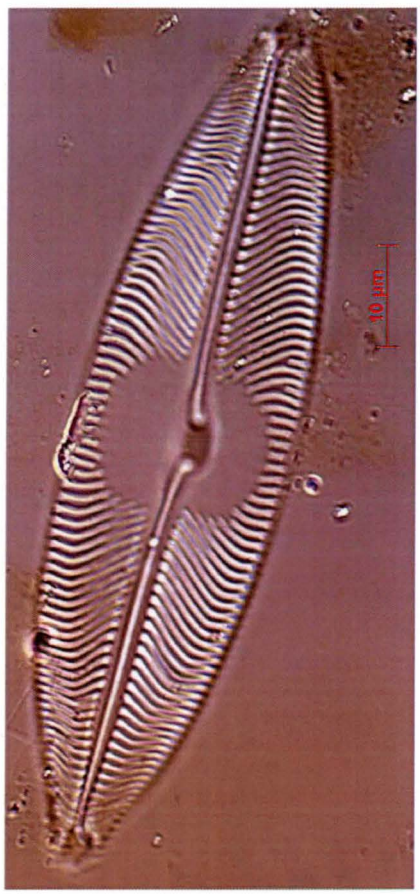

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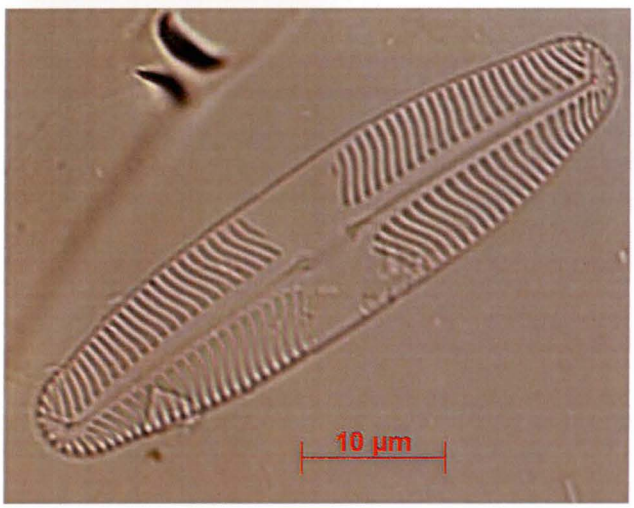

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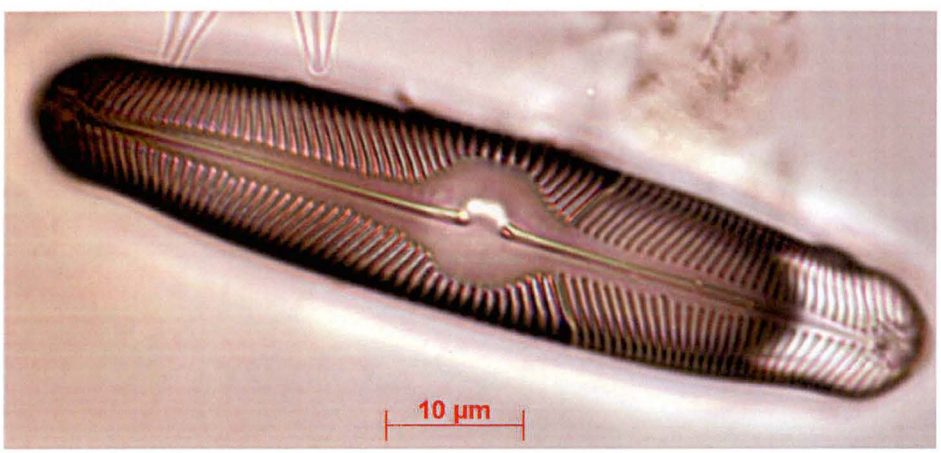
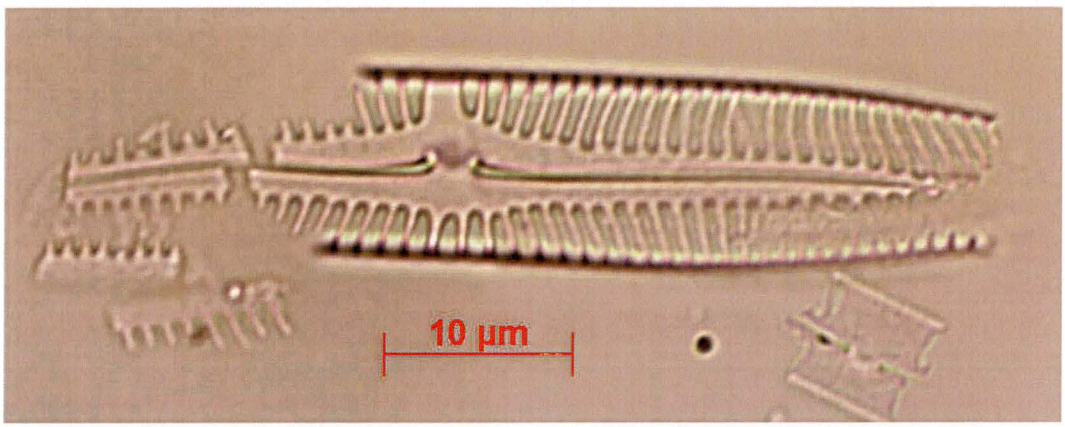


1. *Petroneis* sp. 1
2. *Pinnuavis* cf. *elegans* (W. Smith) Okuno
3. *Pinnularia bottnica* Krammer
4. *Pinnularia decrescens* var. *kerguelensis*

PLATE 15

1



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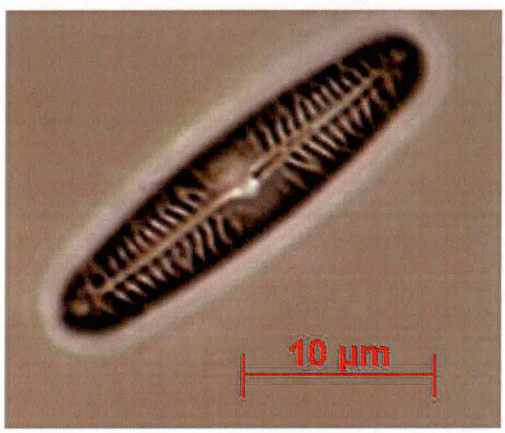

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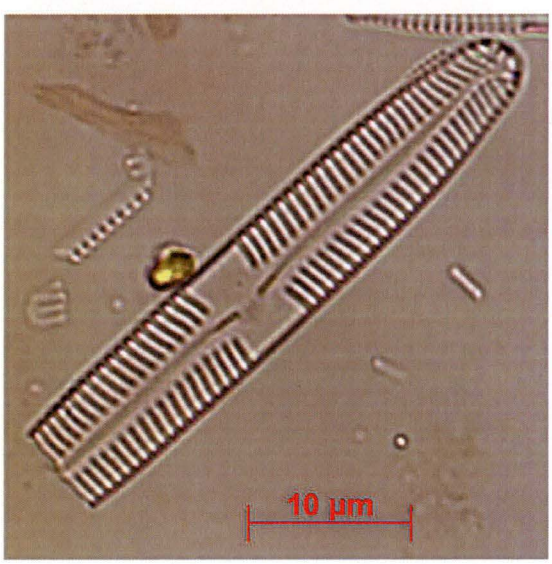
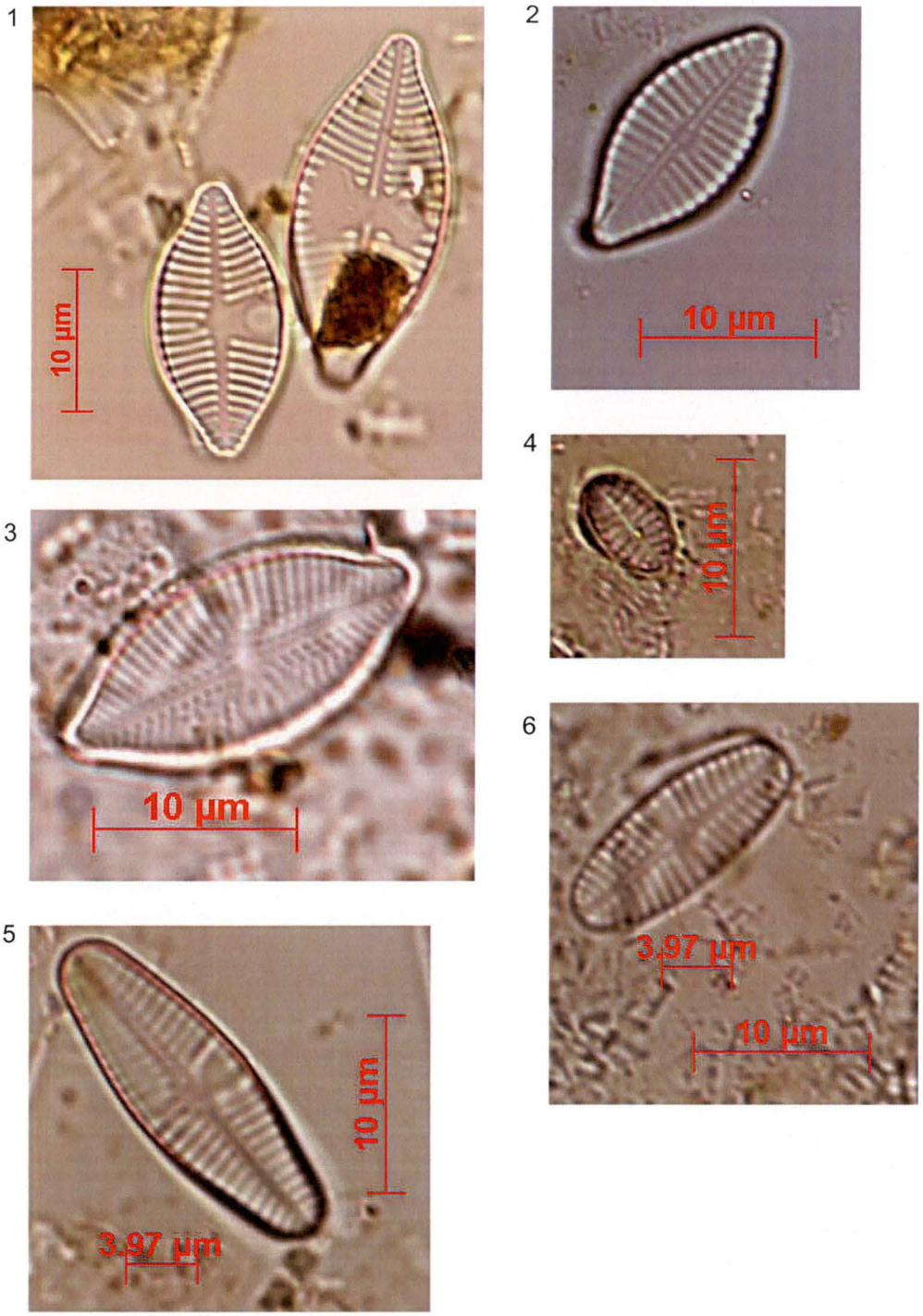
4



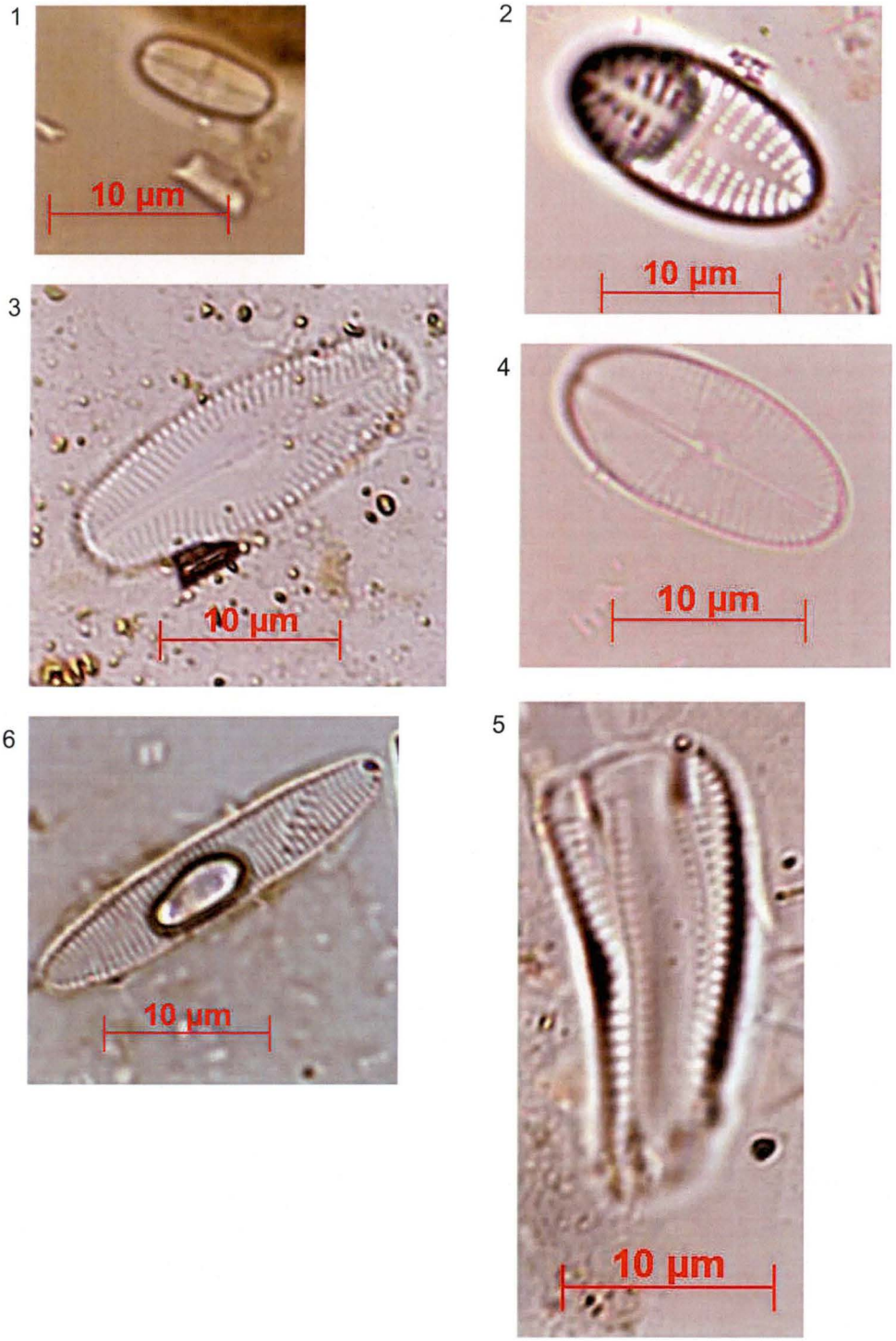
1. *Pinnularia rabenhorstii* (Grunow) Krammer var. *rabenhorstii*
2. *Pinnularia divergentissima* var. *divergentissima* (Grunow) Cleve
3. *Pinnularia rabenhorstii* var. *subantarctica* Van de Vijver & Le Cohu
4. *Pinnularia subantarctica* var. *elongata* (Manguin) Van de Vijver & Le Cohu

PLATE 16



1. *Planthidium cyclophorum* (Heiden) Van de Vijver
2. *Planothidium delicatulum* (Kützing) Round & Bukhtiyarova
3. *Planothidium dispar* (Cleve) Witkowski
4. *Planothidium quadripunctatum* (Oppenheim) Sabbe
5. *Planothidium lanceolatum* (Brébisson ex Kützing) Round & Bukhtiyarova
6. *Planothidium renei* (Lange-Bertalot & Schmidt) Van de Vijver

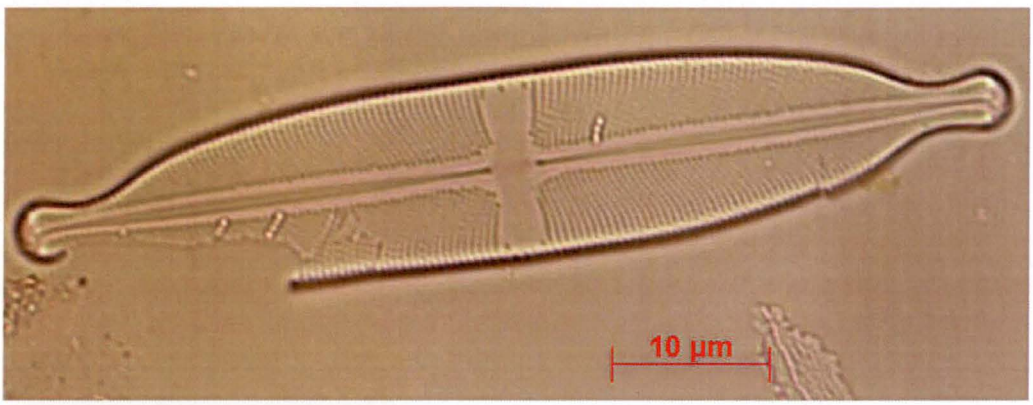
PLATE 17



1. *Psammothidium abundans* (Manguin) Bukhtiyarova & Round
2-3. *Psammothidium oblongellum* (Ostrup) Van de Vijver
4. *Psammothidium oblongellum* var. 1
5. *Rhoicosphaenia marina* (W. Smith) Schmidt
6. *Stauroforma exiguiformis* (Lange-Bertalot) Flower

PLATE 18

1



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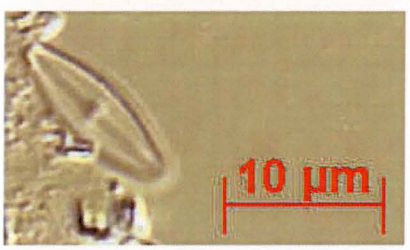

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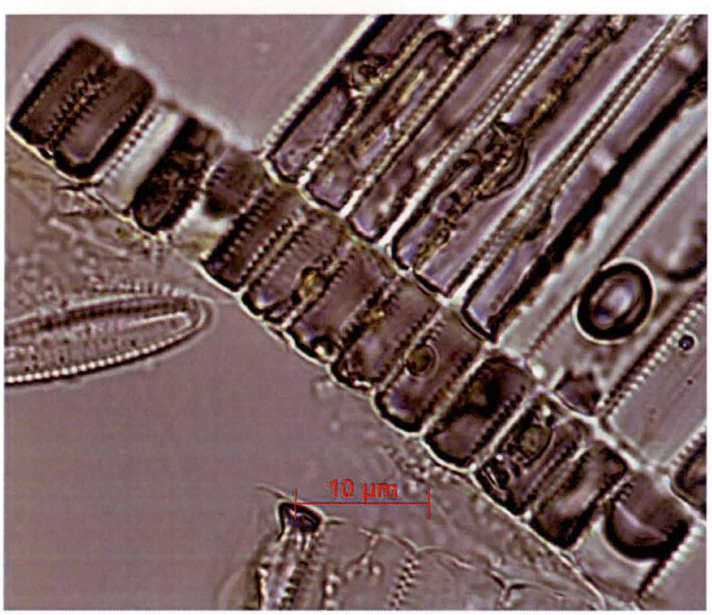

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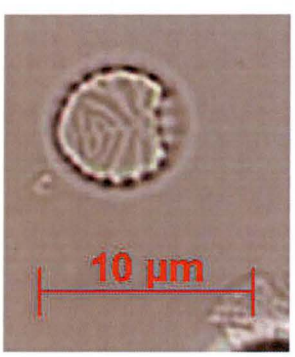
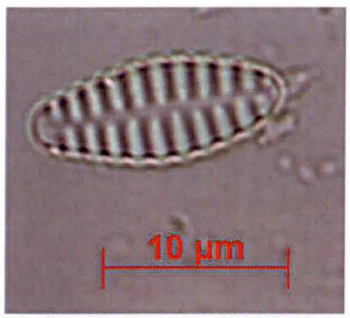


1. *Stauroneis* aff. *phoeniceuferon* (Nitzsch) Ehrenberg
2. *Stauroneis* sp. 1
3. *Staurosira* cf. *alpestris* (Krasske) Van de Vijver
4. *Staurosira circula* Van de Vijver & Beyens

PLATE 19

1



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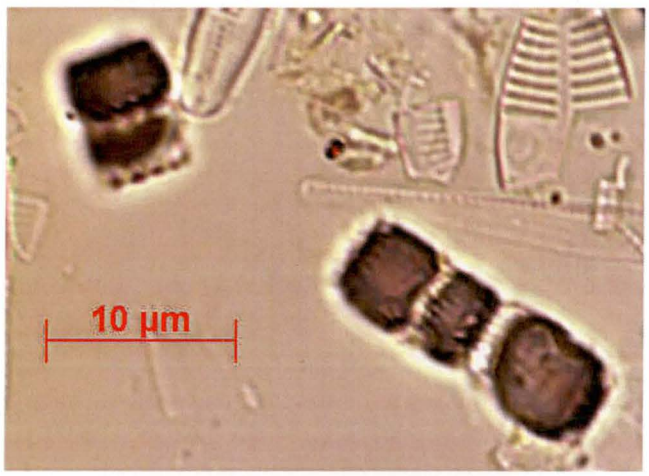

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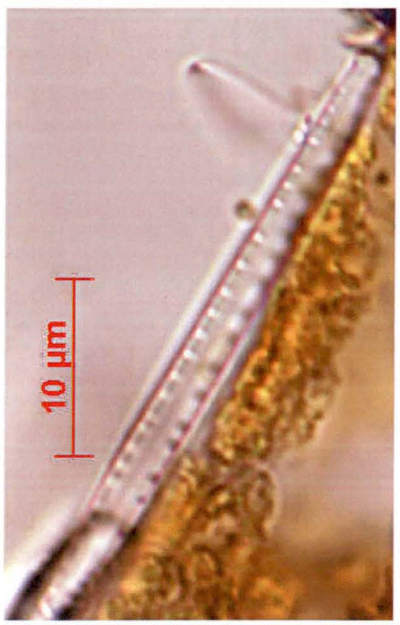
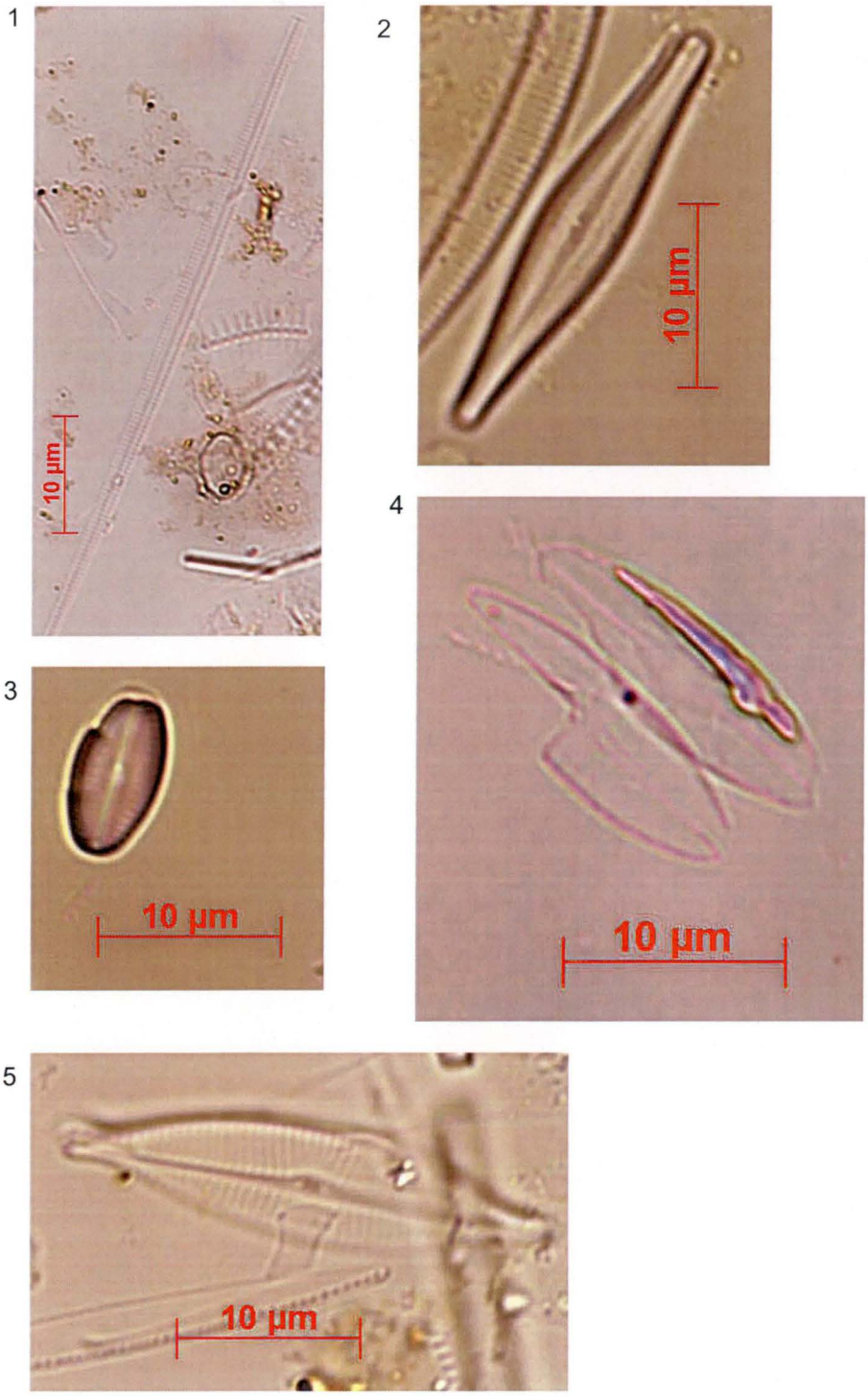


4

1. *Staurosira martyi* (Héribaud) Lange-Bertalot
2. *Staurosira venter* (Ehrenberg) Cleve & Moeller
3. *Stenopterobia curvula* (W. Smith) Krammer
4. *Surirella* cf. *tenuis* Mayer

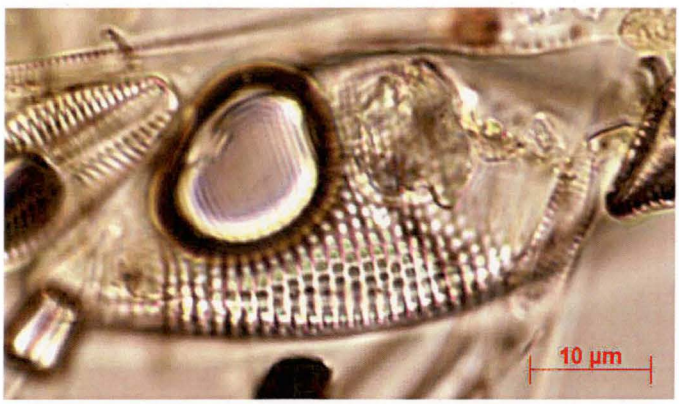
PLATE 20



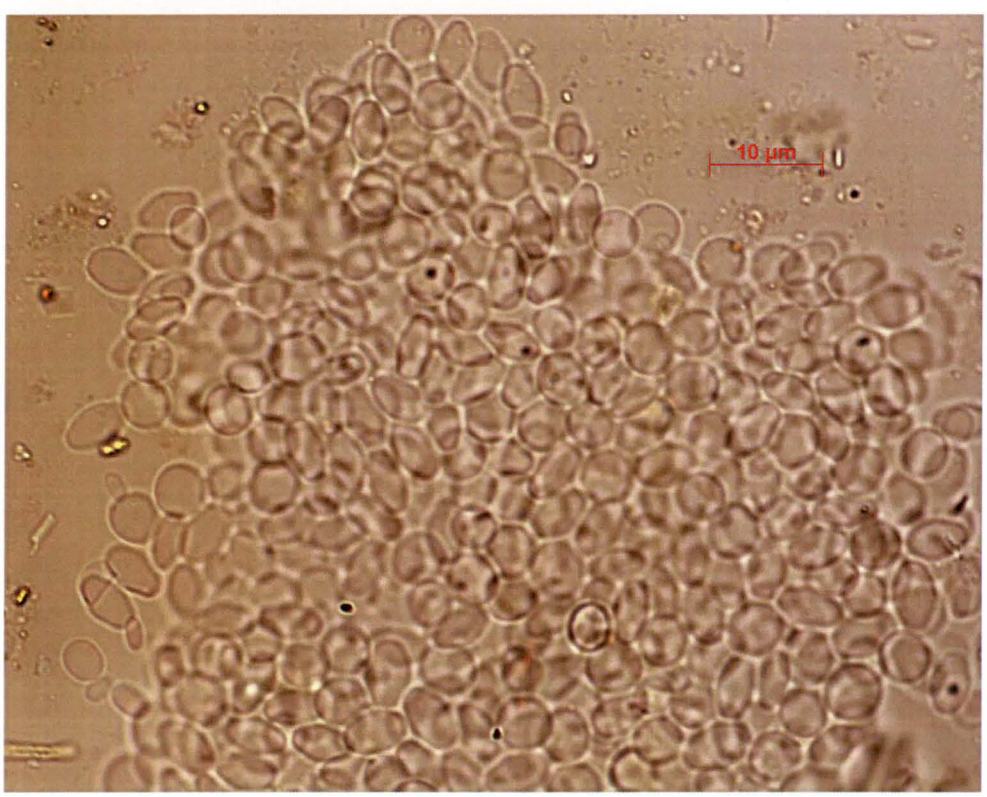
1. *Synedra* cf. *camtschatica* Grunow
2. Unknown sp. 1
3. Unknown sp. 2
4. Unknown sp. 3
5. Unknown sp. 4

PLATE 21

1



2



1. Unknown sp. 5
2. Unknown sp. 6

Appendix 7: Macquarie Island diatom species optima and tolerances

Macquarie Island species optima and tolerances. Note: count = number of occurrences, max = maximum relative abundance (%), N2 = effective number of occurrences, Opt = optima, Tol = tolerance, SRP = soluble reactive phosphate, Sal = salinity, Si = silicate, Temp = temperature.

Code	Count	Max	N2	pH opt	pH tol	SRP opt (µg P L-1)	SRP tol (µg P L-1)	Sal opt (ppt)	Sal tol (ppt)	Si opt (µg Si L-1)	Si tol (µg Si L-1)	Temp opt (°C)	Temp tol (°C)
ACH1	2.00	1.17	1 95	5.96	0 37	651.71	2 80	0.29	0.03	52.65	1.37	10.58	0.04
ACH15	3.00	4.66	1.81	6.03	0 81	397.75	1.89	0.28	0.02	52.50	2.72	10.54	0.07
ACH25	17 00	28.80	9 22	7 20	0 68	211.51	7 74	0 30	0 25	196.12	4.63	7 51	0.16
ACH25a	7 00	7 80	4.83	7.37	0.58	272 54	8.84	0.43	0 28	174 12	2.64	7 54	0 21
ACH25b	1.00	0 25	1.00	7.25	0.60	1461.55	3 97	0.80	0.15	72.27	2 71	6.32	0 17
ACH25c	2 00	1.92	1.57	6.97	1.07	1287.13	4 20	0 33	0 01	214 27	9.51	7.90	0.10
ACH26	17.00	81 25	14 10	7.13	0.67	1084.83	2.00	0.58	0 22	217 02	2.09	7 35	0 19
ACH29	2 00	0.39	1.93	6.71	0.11	850.28	0 09	0.36	0 45	87 35	0.25	6 12	0.16
ACH3	3.00	3 72	2.08	7 62	1.00	129 09	3.25	0.24	0.07	294.29	2.87	9.73	0.14
ACH31	1.00	0.25	1 00	7 25	0.60	1461.55	3 97	0 80	0 15	72.27	2 71	6.32	0 17
ACH31a	4 00	0.50	3.66	7.38	0 10	967.88	0.73	0.48	0 20	366.98	1 83	7 85	0.12
ACH32	13.00	4 81	9.69	7.20	0.86	305 61	7 32	0 44	0.26	151.61	3.06	7.11	0 18
ACH33	1.00	2.27	1 00	7 25	0 60	1461.55	3.97	0.80	0.15	72 27	2 71	6.32	0.17
ACH35	2 00	0.50	1 84	7 44	0 04	1094 72	1.03	0 36	0.01	395.51	0 85	8 39	0.08
ACH38	1.00	8 50	1 00	6 59	0 60	4.81	3.97	0 08	0 15	24 14	2 71	4 86	0 17
ACH38a	2.00	7.25	1 26	6.84	1.53	7.57	9 62	0 09	0 04	35 71	8.97	5 09	0 26
ACH40	3.00	0 75	2 78	7 64	0.69	8.56	4.99	0.07	0.04	57.67	4.63	7 67	0.06
ACH41	7 00	8.73	5.88	6 96	0 56	6.14	2.40	0.06	0 03	20 37	5.91	7 77	0 23
ACH42	5.00	2.65	3 89	6 42	0.58	3.88	3.91	0.04	0 04	20 39	8.66	8 99	0 26
ACH4c	3 00	5.50	2 08	7 08	0.58	313 66	0 65	0 47	0 31	593 50	5.02	7 28	0.18
ACH5	1 00	14.36	1.00	7.57	0 60	155.44	3 97	0 47	0 15	201 90	2 71	6.83	0.17
ACH5d	1.00	0.24	1.00	6.73	0.60	1029.93	3 97	0 60	0 15	73.93	2.71	8.57	0.17
ACH6a	1 00	0.47	1.00	5.74	0 60	294 20	3 97	0 27	0 15	31 11	2.71	10 83	0 17
ACHbre	2 00	1.00	1.56	6.44	0.54	1189.58	3.39	0.31	0.01	204.51	5.68	9.52	0.22
ACHpse3	7 00	1 90	5.78	7.16	0 51	10.17	4.83	0.09	0.05	10.92	1.61	6.16	0.45
ACHpse4	3 00	9 71	1.35	7.34	0 77	4 91	3.63	0.10	0.02	86.50	2.40	7.33	0.02
ACHpse5	2 00	2.67	1.41	7.48	1 09	8 20	10.86	0.11	0.02	107.75	3 64	7.31	0.02
ACHpse6	1.00	0 23	1 00	7.08	0 60	3.34	3 97	0 13	0.15	11 81	2 71	7.87	0 17
ACHres3	3 00	0 29	2.98	6.45	0.64	4 70	23.46	0 13	0 11	21 58	4 78	7 79	0 36
ACHres3a	1 00	0.24	1.00	6.73	0 60	1029.93	3.97	0.60	0.15	73.93	2.71	8.57	0 17
ACHsub	31.00	62.50	20 64	6.88	0.83	9.67	14.26	0.14	0.18	20.78	3.58	7.60	0.28

Code	Count	Max	N2	pH opt	pH tol	SRP opt (µg P L-1)	SRP tol (µg P L-1)	Sal opt (ppt)	Sal tol (ppt)	Si opt (µg Si L-1)	Si tol (µg Si L-1)	Temp opt (°C)	Temp tol (°C)
ACHsub1	7 00	9.62	5 85	6.76	0.31	23.60	29.03	0 17	0.12	57.74	2.48	6 57	0.16
ACHsub2	23.00	95 06	18 72	7 00	0.48	3.43	2.58	0.09	0 03	19.08	2.82	6 53	0.20
AMP1	2.00	0 57	1 78	7.46	2 60	104 03	0 86	0.22	0.11	228.18	19 59	9 09	0.46
AMP11c	10.00	2 57	6.88	7.55	0.29	41 97	11 52	0.33	0.33	72 96	5.46	7.00	0 22
AMP18a	15.00	6 98	10 38	6.97	0.57	2.46	2 16	0.06	0.04	10.21	2 69	7.82	0 26
AMP22	7.00	1.44	6.13	7 34	0.51	8.56	3 79	0.11	0.03	16.68	2 32	6.16	0.24
AMP23	3 00	13 72	2.32	7.55	0.65	7.23	4 16	0.07	0.03	38.74	4.78	7.62	0.06
AMP4	2.00	3.40	1 29	7.18	0.16	5 15	2.18	0.10	0.01	72 72	0 04	7.14	0.15
AMPcof	2 00	1.54	1 78	8 32	0 86	33 88	7 74	0.11	0.04	162.87	32 78	7.13	0.03
AMPlae	1 00	0 25	1.00	6.48	0.60	0.22	3 97	0.07	0.15	2.88	2.71	8 47	0.17
AMPven	1.00	5.52	1 00	6.27	0.60	78 06	3.97	0.27	0.15	918 18	2 71	7 48	0.17
AULgra	1 00	2 33	1 00	5 74	0 60	294.20	3 97	0 27	0.15	31 11	2.71	10.83	0 17
AULita	1.00	6.29	1.00	5.74	0.60	294 20	3 97	0.27	0.15	31 11	2 71	10.83	0.17
AULval	1 00	5.13	1 00	5 74	0.60	294.20	3 97	0.27	0.15	31 11	2 71	10.83	0.17
CEN15	5.00	52 88	2 16	6 93	0 70	1463.43	3.76	0.35	0.12	120 97	1 36	7 84	0.09
CEN16	5.00	50 00	3 99	6 70	0.22	11 92	22.09	0.23	0.34	22 41	2.76	6.08	0.19
CEN16a	15 00	75 18	10 36	6.71	0.55	2.73	1 55	0.06	0.04	13.73	2 11	7.71	0 27
CEN17	5 00	42 65	2 88	6 83	0.44	1.43	0 79	0.10	0.03	8.25	2.55	7.21	0 10
CEN18	1.00	0.28	1 00	7 50	0 60	3 39	3 97	0.07	0.15	4 66	2 71	7.34	0.17
CEN5	2.00	1.25	1 51	8 17	0 64	747.91	0.93	0.38	0 02	286.75	0.01	8.75	0.00
COC13	5.00	2.50	3.38	6 31	0 46	13 21	34.18	0 20	0.21	12 01	4.71	8.84	0.20
COC13a	14 00	13 45	9 60	7 16	0.41	7.86	2 93	0.08	0.04	14 78	1.88	6.18	0 30
COC15	4.00	1.10	3 17	8.14	0.75	36.55	7.34	0 14	0 13	120 90	11.29	7 42	0.08
COC15a	3 00	5 45	1 73	8 33	1.08	64 04	10 29	0.13	0.00	203 53	17 63	6.94	0.18
COC8	12 00	49 76	8 04	8 29	1 09	39 12	6 26	0 12	0.06	84.93	7.42	8 25	0.27
COC8a	7.00	5.51	4 48	8.05	0.90	40 57	4 18	0.12	0.02	238.33	7 47	7.18	0.08
COCdis	1.00	1 01	1 00	7.25	0 60	1461.55	3 97	0 80	0.15	72.27	2.71	6.32	0.17
COCpla	9.00	7.46	6 07	6 87	0 83	526.85	2 08	0.51	0.26	82.06	1.18	7.54	0.25
COCscu	1.00	1.74	1.00	7 46	0 60	1557.55	3 97	0.36	0.15	291.17	2.71	8 73	0.17
CYCmen	2 00	9.07	1 18	6 65	0.70	928.09	1 42	0 57	0 23	68.83	0 82	8 74	0.16
CYCstr	8 00	6.74	4 20	6 52	0 65	101.67	9 56	0.24	0 18	65.19	4.21	6 68	0.19
CYMasp3	2.00	5 50	1.24	6 48	0 01	0.19	0 15	0 07	0.15	2.79	0.16	8.47	0 00
DELmin	1 00	0 75	1.00	6.98	0 60	24 49	3 97	0.08	0.15	69 55	2 71	5 86	0.17
DIP10a	2.00	0.26	2.00	7.64	0.25	871.87	1.24	0 59	0.32	111.12	2.79	6.90	0.34
DIP10b	2.00	0 25	2.00	8.25	0 16	507 25	0 31	0.39	0.01	352 45	0.36	10.67	0.30
DIP11	5 00	1 92	3.24	7.36	0 14	12 05	2 13	0.12	0.01	13 86	1.09	5.04	0 24

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DIPnot	1 00	0 25	1 00	6 47	0.60	0.00	3.97	0 07	0.15	2.15	2.71	8.44	0.17
DIPnot5	3.00	0.45	2.80	7 63	0.26	863 23	0.61	0.50	0.19	666.88	0.95	9.02	0.13
EUNdio	1.00	0.25	1 00	6 48	0 60	0 22	3 97	0 07	0.15	2.88	2.71	8 47	0.17
EUNnae	3.00	1 25	2 90	6 57	0 37	17 56	17 66	0 20	0.14	105.48	32 54	7.89	0.07
FRA12	1.00	2.24	1 00	8 75	0 60	163.12	3 97	0 13	0.15	648.41	2.71	7 10	0.17
FRA13	1.00	0.21	1 00	7 39	0 60	18 06	3 97	0.12	0.15	5.90	2.71	4.50	0 17
FRA2c	1.00	0.49	1.00	9.95	0.60	188.60	3.97	0 12	0.15	11.75	2.71	13.48	0 17
FRA3	12 00	6 97	8.48	7 18	0 42	145.95	11.48	0 22	0.23	37.97	3.62	6 09	0.31
FRA3a	8.00	2.88	5.55	7.50	0.83	21.49	5.22	0.11	0.04	36 35	5 26	5.57	0 23
FRA5	6.00	0 67	5 29	6 68	0 52	17.00	27.57	0.08	0.13	11.61	3 64	8.73	0.29
FRA7	1.00	1.26	1.00	7.25	0.60	1461 55	3.97	0.80	0.15	72 27	2.71	6.32	0.17
FRA8	50.00	98.75	40.41	7 32	0 73	132.97	7.37	0 32	0.22	191.82	5 63	7.48	0.24
FRA8a	12.00	48.37	9 98	7 69	0 48	123 83	5 23	0 31	0.20	182.12	8 08	7 36	0 42
FRAcap2	4 00	79.45	2 10	7 20	0 60	2 44	2 67	0 11	0.05	40 08	3.51	7.21	0.06
FRAque	4 00	0 71	3 48	6 86	0 95	367 34	1 73	0.47	0.27	83.38	0 82	6.60	0.24
FRAvir	1 00	0 24	1.00	7 57	0 60	155.44	3.97	0 47	0 15	201.90	2.71	6.83	0 17
FRUrho	2.00	3.25	1.94	6 48	0.01	0.12	0.15	0.07	0 15	2 56	0.16	8.46	0.00
GOMang	15.00	6 10	10.59	7 36	1 27	316 05	6 40	0 47	0.26	104.43	5 03	8 20	0.24
GOMang1	3 00	5 78	1.93	6.84	0 51	798.10	0 35	0 13	0.30	137.86	3.22	5 99	0.24
GOMang2	6.00	8 01	2.87	8.41	0.88	64.60	5 30	0.12	0 04	352 89	5.67	7.32	0.13
GOMang3	7.00	8.01	4.87	8.08	0.83	35.51	7.69	0 15	0 13	269.56	3.71	7.24	0.05
GOMang4	1.00	0 23	1.00	7.26	0.60	61.84	3 97	0 10	0 15	1525.83	2 71	8.29	0.17
GOMang5	1.00	0.23	1.00	7 26	0.60	61.84	3 97	0 10	0 15	1525.83	2 71	8 29	0.17
GRA3	1 00	0 32	1.00	7.10	0 60	2 27	3 97	0.13	0.15	8.91	2.71	7.45	0.17
GRA4a	3.00	0.32	2.96	7.02	0.38	5 05	1.09	0 11	0 03	14 79	0 63	5 63	0.27
GRAarc	1 00	0.47	1.00	5.74	0.60	294 20	3.97	0.27	0.15	31 11	2.71	10.83	0.17
GRAoce	1.00	0.24	1.00	7.47	0.60	526.90	3.97	0.79	0.15	169.75	2.71	6 33	0.17
NAV10	2.00	1.40	1.47	6.58	2 98	269 31	0 37	0.24	0.11	25.72	0 92	11.32	0.15
NAV32c	15 00	74 28	8.62	6.78	0.38	1.44	1.21	0 05	0.04	6.86	1.72	7 96	0.27
NAV42	3.00	4.00	2.51	6.21	0.56	808.39	2.23	0 29	0.02	76 85	1.32	10.28	0.06
NAV50	10 00	1.91	7 61	6 91	0 60	335 48	3 36	0.38	0.30	103.49	1 82	6.62	0.20
NAV50c	7.00	3.55	5.18	6.83	0.66	256.39	11.18	0 33	0 15	175.82	6.79	7.21	0.14
NAV50e	2.00	0.71	1 70	6 14	0 14	43.25	42.32	0.20	0.20	37 49	6.45	7.52	0 49
NAV52	2.00	0.35	1.95	8.12	1.70	567.53	1.06	0 48	0.14	500.53	9.11	9 05	0 06
NAV52a	2.00	0 25	1.98	6.89	0.15	117.70	10.53	0 32	0 38	81.59	0.28	6 24	0.09
NAV54	2.00	0.99	1.84	7.60	0.28	1218 86	0.64	0 47	0 22	459.00	1 50	9 16	0.09

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NAV54a	3.00	0.49	2.73	7 24	0.18	21.61	24 28	0.18	0.14	68.26	3 12	7.83	0.08
NAV54b	6.00	1.14	5.76	6.94	0.49	3.74	1.52	0 09	0.02	8 34	0.81	5.89	0 21
NAV55	15.00	2.94	10.48	7 09	0.53	7 58	6.52	0.12	0.09	18 91	3 47	6.42	0.27
NAV55a	1.00	0.42	1.00	7.39	0.60	18.06	3.97	0 12	0.15	5.90	2 71	4.50	0.17
NAV57	11.00	4.51	8.65	7 15	0.40	5 12	3.63	0 10	0.07	16.08	3.25	6 55	0.21
NAV57a	1.00	1.94	1.00	7.10	0.60	2.27	3.97	0 13	0.15	8.91	2 71	7 45	0.17
NAV58	3.00	0.73	2.68	7 71	0.44	595.05	0 79	0.37	0.01	498.28	0.50	9.85	0.32
NAV59	4.00	0.96	2.98	7.04	0.58	227.33	29.83	0 33	0.30	75.93	0 42	7.24	0.15
NAV60	1 00	1.95	1 00	7 41	0 60	570 68	3 97	0.37	0.15	695 80	2.71	7 78	0.17
NAV61	4.00	1.72	3 02	7 04	0 42	1194 14	1 41	0.58	0.26	303.38	2 69	7 48	0.06
NAV61a	6.00	9.56	3 37	7 27	0 69	1343.90	1.24	0 68	0.19	338.80	2 29	8 29	0.15
NAV61b	2 00	2.25	1 77	7.83	1 18	994 31	1.93	0.53	0 31	216 75	0 84	8.27	0 12
NAV62	1 00	0.78	1 00	6 77	0 60	807 80	3.97	0.62	0.15	99 53	2.71	6.75	0 17
NAV63	13 00	52.66	8.94	6.94	0.39	2.65	1 51	0 06	0.03	7.94	1 05	7 29	0.24
NAV64	2.00	0 32	1 95	7.09	0.01	2 69	0.22	0 13	0 15	10 05	0.20	7.63	0.03
NAV65	4.00	2.54	3.05	6 99	0 68	3 22	0 86	0.07	0 01	8 99	1.38	6.72	0 16
NAV66	7 00	3 67	5.19	7.02	0.61	4 06	1 13	0.07	0.02	18.48	2 37	7.06	0.19
NAV67	2 00	1 41	1.91	7 22	0 50	1 72	1 39	0.07	0 15	3 85	0 33	6.96	0.09
NAVcon	1 00	3 00	1 00	6.47	0 60	0 00	3.97	0.07	0 15	2 15	2 71	8.44	0 17
NAVcry	1 00	0 23	1.00	5 74	0 60	294.20	3.97	0.27	0 15	31.11	2.71	10 83	0.17
NAVgot	2 00	5 75	1.64	6.48	0 01	0 16	0.15	0.07	0.15	2 67	0.16	8.46	0.00
NAVmut	2 00	1 50	2.00	6.48	0 01	0 10	0.15	0.07	0 15	2 50	0.16	8.45	0.00
NAVniv	1 00	2.00	1 00	6.47	0 60	0 00	3.97	0.07	0 15	2 15	2.71	8 44	0.17
NAVper	5 00	0 85	4.53	6.93	0.81	16.62	9.78	0 14	0 11	41.89	5 23	7.31	0.29
NAVper2	2.00	2.94	1 97	5 99	0 78	396 01	7.90	0 58	0 32	85.96	0 15	7.22	0.06
NAVryn	2 00	0 21	1 98	7.40	0.60	71.88	4.22	0 24	0.06	386.54	0 10	9.52	0 03
NAVryn3	1.00	0.24	1.00	7.57	0.60	155.44	3 97	0 47	0.15	201.90	2 71	6.83	0.17
NAVryn5	7.00	2.43	5.06	7.42	0.29	212.79	8.12	0 42	0.29	354.57	3 34	7.43	0.19
NAVryn6	5.00	1 92	3.78	7 49	1.15	599.66	2.92	0 29	0.12	220.71	1 84	7.75	0.11
NAVryn7	1.00	1 96	1 00	5 50	0 60	101 24	3.97	0.78	0.15	78.74	2 71	6.93	0.17
NAVvir	1.00	1 25	1 00	6 48	0 60	0 22	3.97	0.07	0 15	2 88	2.71	8.47	0.17
NIT4b	3 00	1 21	2 35	7 25	0.64	106.36	31 92	0.58	0 40	76.14	12.12	6.90	0.20
NIT6	12.00	9 58	6.68	7 20	1.18	40 16	8.56	0.31	0 32	35.57	4 35	7.32	0.18
NIT6a	11.00	3 51	7.10	7 51	1 20	138.32	9.59	0.35	0.31	48.86	3 53	7.09	0.34
NIT6c	6.00	1.50	5.30	7.04	0.31	3.62	0 59	0.07	0 02	20 66	1.51	6.95	0.17
NITscal	5.00	1.46	3.31	7.23	0 52	121.24	20 29	0.51	0.43	51.50	4.58	6.46	0.16

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OPE3c	11 00	9 93	9.15	7.02	0.25	2.03	1.88	0.08	0 02	32.76	4.13	6.46	0.18
OPE9	16.00	30.14	9 65	7 11	0.79	92.71	7.60	0 23	0 22	65 72	3.53	6 16	0 21
OPEbur	1 00	5 98	1.00	7.03	0.60	239 86	3.97	0.32	0 15	1596.09	2.71	7.48	0.17
OPEgue	9.00	12.82	6.51	6.80	0 77	116.97	5.66	0.25	0 23	62.34	4 75	6.74	0.36
PARsul	1 00	0 75	1.00	6.48	0.60	0 22	3.97	0.07	0 15	2 88	2.71	8.47	0.17
PIN4	8 00	1 50	6.05	6.70	1.02	50 86	21 53	0.20	0 12	35 88	10 24	8 81	0 25
PIN4a	3 00	0.45	2.81	7.60	0 29	1066.16	0.46	0.50	0.19	938.92	1 69	9.09	0.11
PIN4b	3 00	1 25	2.42	7.33	0.23	8 52	1.63	0.09	0.04	15.36	3.06	5.98	0.39
PIN5	5 00	1 29	3.98	6.99	0 47	3 25	0.95	0.09	0.04	10.48	1 03	6.53	0.31
PLAdel	3.00	4.85	1 88	7.47	0.44	545.84	0 27	0 72	0 33	116 35	1 31	6.03	0.10
PLAfre2	1.00	0 26	1 00	7.82	0.60	496 76	3 97	0 81	0.15	43 33	2 71	5.45	0.17
PLAfre3	39.00	34.47	24.84	7 29	1.00	356 20	6 30	0 37	0.25	164.82	3 74	7.99	0.23
PLAfre4	6.00	6.91	2.70	7.57	0 68	89.80	5.27	0.15	0.13	652.51	3.91	7.86	0.18
PLAhau	24 00	70 44	14.97	6.85	0 70	132.12	10.29	0.41	0.34	83.56	2.23	6 81	0.19
PLAhau3	10 00	5 54	7 51	7 11	0.61	1223 42	1 68	0 60	0.23	226.59	3 19	7 60	0 17
PLAhau3b	1 00	7.79	1 00	6 61	0.60	916 72	3 97	-0 01	0.15	72.08	2.71	5.29	0.17
PLAhau3e	1.00	0.50	1 00	6 61	0.60	916.72	3.97	-0.01	0 15	72 08	2 71	5 29	0.17
PLAlan	1.00	0 24	1.00	7 47	0.60	526 90	3.97	0 79	0 15	169 75	2.71	6 33	0 17
PLAmar	5.00	1.96	4 08	7 27	0.19	10 94	2 00	0.08	0 03	63 72	3.48	6 52	0 28
PLApol2	3 00	1.75	2 15	7.33	2.11	787 91	3.91	0 29	0 15	69.24	2 87	10 39	0.28
PSEsep	2 00	4.00	1.99	6.02	0.37	811 38	2.80	0 29	0 03	60.80	1 37	10.51	0.04
STAacu	1 00	0.50	1 00	6.26	0.60	1951 18	3 97	0 31	0 15	107.96	2 71	10 24	0 17
SYN5	5 00	47.00	2.79	6 25	0.66	656 13	3.18	0.29	0.03	82.98	1.74	10.29	0.06
SYNcam	2 00	2.86	1.32	6.69	0 18	384.73	134.11	0.52	0.37	46.82	8 40	8.55	0.01
UNK10	1.00	3.00	1 00	6.47	0.60	0 00	3 97	0 07	0.15	2 15	2.71	8.44	0.17
UNK100b	3.00	4.66	1.39	5.98	1.06	239.00	2 87	0 26	0.04	44.07	3 45	10.61	0.09
UNK107	2 00	0 49	1.86	6.89	0 40	2218 17	0 59	0 82	0.02	100 02	0.43	6 94	0.09
UNK107d	3.00	0 49	2.79	7.16	0.47	353.81	22.84	0 66	0 36	121.78	0.54	6.92	0.08
UNK117a	7 00	3.16	5.64	7.20	0.66	459.50	1.20	0 53	0.21	188.05	2.41	8.00	0.24
UNK117c	1 00	4.50	1.00	6.48	0 60	0 22	3.97	0.07	0.15	2 88	2.71	8.47	0.17
UNK19a	1 00	0.50	1.00	6.48	0.60	0 22	3.97	0.07	0.15	2.88	2.71	8.47	0.17
UNK19c	2 00	1.47	1.45	6.96	0.20	2 89	130 41	0 18	0 37	88 47	0.17	5 99	0.32
UNK205a	1 00	0.71	1.00	6.08	0.60	205.36	3.97	0 28	0 15	86.41	2.71	6 24	0.17
UNK205b	1 00	0.96	1.00	8.75	0.60	163.12	3 97	0.13	0 15	648 41	2.71	7 10	0.17
UNK3	3.00	0.73	2 74	6 92	0 42	1.79	1.16	0.06	0 06	29.62	4 96	7.81	0.32
UNK30	5.00	0.98	4.76	6.86	0 72	38.97	21.95	0.41	0 36	25.37	5 41	6.55	0.13

Code	Count	Max	N2	pH opt	pH tol	SRP opt (µg P L-1)	SRP tol (µg P L-1)	Sal opt (ppt)	Sal tol (ppt)	Si opt (µg Si L-1)	Si tol (µg Si L-1)	Temp opt (°C)	Temp tol (°C)
UNK302	7.00	0 50	6 51	6.95	0.59	655 60	0.91	0.47	0 33	99.14	1.27	6.51	0.18
UNK302a	3 00	1 28	2.30	8 50	0.74	81.80	4.10	0 13	0 01	492 79	1 96	7.12	0.02
UNK303	3.00	0 26	2.99	7 45	0.34	116.28	14.63	0 50	0 37	138.56	4 18	6.85	0.20
UNK303b	1.00	0.65	1.00	7 10	0.60	2 27	3.97	0.13	0.15	8 91	2 71	7.45	0.17
UNK304	2.00	1 26	1 99	6 70	0 83	580.94	2 99	0.56	0.37	78.61	0 13	6.28	0.01
UNK305	2.00	0.76	1 68	7 31	0 15	1488.05	0 05	0 68	0.31	107.31	1.66	6 93	0.22
UNK307	2.00	0.49	1.86	7 62	0.81	27 21	29.10	0 20	0 21	119 79	1.60	7.83	0 12
UNK307a	2.00	0.25	2 00	6 90	0 44	4 38	0 12	0.09	0.01	41.88	1 15	5 98	0.28
UNK307b	2.00	0.24	1.99	7.37	0.02	15.22	0.24	0.12	0.15	10 45	0 96	4.49	0.00
UNK308	10.00	3.44	6.97	7.20	0.57	5.49	4.96	0 09	0 08	19.44	3.39	6 67	0.22
UNK308a	4.00	3 46	2 92	7 29	0 36	15.58	4 52	0.09	0.04	72.72	29 37	7 47	0.29
UNK309	5.00	3.42	3 90	7 23	0 39	2 91	0 82	0 08	0.02	22.66	3.54	7.36	0.14
UNK310	1.00	64 72	1 00	7 10	0.60	2.27	3 97	0 13	0.15	8.91	2.71	7 45	0.17
UNK311	1.00	0.21	1 00	7 39	0 60	18.06	3 97	0 12	0 15	5.90	2 71	4.50	0 17
UNK37b	15 00	11.74	10 82	7 28	0 52	6.39	4.00	0 12	0.10	26 91	4.02	6.43	0.20
UNK57	5.00	3.24	3 72	7 05	0.31	2 05	1 06	0.08	0.03	8 84	0 79	7 26	0.09
UNK57b	6 00	56.25	3 83	6 67	0.45	0 77	1 63	0.07	0.01	3.55	0 83	7.71	0 18
UNK62	1.00	0 50	1 00	6 47	0 60	0.00	3.97	0.07	0.15	2.15	2 71	8.44	0.17
UNK70a	1.00	1 50	1.00	6.26	0 60	1951 18	3 97	0.31	0.15	107.96	2.71	10 24	0 17
UNK80	1 00	0 23	1 00	5 74	0 60	294.20	3 97	0.27	0.15	31 11	2 71	10.83	0.17
UNK87c	8 00	13.37	5.35	6 72	0 67	69 75	21 25	0 45	0.33	35.48	3 07	7 03	0.17
UNK87d	2 00	5 35	1.39	7 46	0 17	5 90	5.57	0.08	0.02	13 67	51 36	7.49	0 08
VIKpro	2 00	0 25	2.00	6.12	0 52	14 71	54 80	0.17	0.14	8 70	4 16	9.53	0.17
VIKpro3	1.00	0.49	1.00	7.21	0.60	3.97	3.97	0 10	0.15	73.21	2.71	7 35	0.17

Palaeolimnology as a Management Tool for Australian Aquatic Ecosystems

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ORIGINAL PAPER

Palaeoecological tools for improving the management of coastal ecosystems: a case study from Lake King (Gippsland Lakes) Australia

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Abstract Since European settlement began over 200 years ago, many southeast Australian coastal lakes and lagoons have experienced substantial human impacts, including nutrient enrichment. Present day management and conservation efforts are often hampered by a lack of data on pre-impact conditions. We used a palaeoecological approach at Lake King, Gippsland Lakes, southeast Australia in order to determine its pre-impact condition and to establish the nature and direction of subsequent environmental changes, including responses to the construction of a permanent entrance to the sea in 1889. A 120 cm sediment core was analysed for diatoms, chlorophyll *a*, total carbon, nitrogen and sulphur, and dated using ^{210}Pb. Past phosphate and salinity concentrations were reconstructed using diatom-phosphate and diatom-salinity transfer functions developed from a calibration set based on 53 sites from 14 southeast Australian coastal lakes and lagoons. Results show changes in the diatom assemblage that record a shift from a brackish-water to marine diatom flora since construction of the permanent entrance. Phosphate concentrations increased at the same time and experienced major peaks in the 1940s and 1950s to >100 µg/l. Chlorophyll *a* concentrations were generally below 24 µg/l/gTOC in the core, but there has been a clear increase since the 1980s, peaking at 120 µg/l/gTOC, likely associated with a recorded increase in the frequency of nuisance algal blooms. These results indicate that the Lake King environment is now very different to that present during early European settlement. We conclude that by identifying the nature and direction of environmental change, palaeoecological studies can contribute towards developing realistic and well-informed management, conservation and restoration strategies in Australian coastal ecosystems.

Keywords Diatoms · Human impacts · Coast · Nutrients · Radionuclide dating · ^{210}Pb

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Introduction

Coastal zones around the world are under unprecedented pressure from human activities, particularly from increasing population pressure and competing demands for resources. Much of the Australian coastline is renowned worldwide for its 'pristine' and natural state, however many areas, particularly

coastal lakes, lagoons, shallow bays and estuaries, have been extensively modified, and in some cases heavily degraded, over the last 200 years since European settlement due to changed land and water management practises.

About 70% of Australia's coastline is sparsely populated, but 85% of the population lives within 50 km of the sea, and is particularly concentrated along the south and east coasts, resulting in major pressure on these environments (Harvey and Caton 2003). In many areas extensive development of coastal catchments has led to declining water quality, eutrophication, reduction and degradation of important seagrass, mangrove and saltmarsh habitats, disruption of migratory bird populations and declining fish populations (SoE 2006). Despite this, many remain important conservation areas. Thirteen of the 64 Ramsar listed sites (i.e. sites recognised as 'Wetlands of International Importance') in Australia occur on the southeast (i.e. Tasmanian and Victorian) Australian coastline (Environment Australia 2005).

Globally, the conservation and management of coastal areas have often lagged behind terrestrial environments. One of the major problems for management is that few coastal ecosystems have been consistently monitored for more than a decade, which means that long term data spanning the full period of human impacts does not exist (Tibby 2004). This limits attempts to determine the magnitude and direction of water quality changes and limits the ability of managers to devise appropriate management and conservation strategies (Vaalgamaa and Korhola 2004). Most importantly, successful management of coastal waters requires knowledge of the original or pre-impact condition of the environment and the range of natural variability (Weckström et al. 2004).

Palaeoecological approaches have been widely used in freshwater lake systems and to a limited extent in coastal systems, particularly in the Northern Hemisphere (e.g. Ellegaard et al. 2006; Weckström et al. 2004). For example, palaeoecological studies have been used to bring about a commitment to reverse eutrophication in Chesapeake Bay, USA through increased political and public awareness (Kemp et al. 2005). Similarly, in Europe, a palaeoecological approach has been adopted to help define reference conditions in European estuaries as part of the European Union Water Framework Directive (e.g. Andersen et al. 2004; Clarke et al. 2003; Weckström et al. 2004). In contrast, the application of a palaeoecological approach to understanding coastal systems in the Southern Hemisphere, and Australia in particular, is still very much in its infancy (Hodgson et al. 1996; Saunders et al. 2007; Taffs et al. in press). Political awareness of the need to define reference conditions and assess the changes that have occurred since European settlement has increased in recent years, but as yet a palaeoecological approach has not been adopted as a method to address these issues. This is surprising as Australian aquatic environments, including coastal lagoons and estuaries, are well suited to palaeoecological studies as significant changes have occurred over relatively short time scales (i.e. ~200 years) as a result of increased human impacts. Similarly, there are also some virtually pristine coastal lagoon and estuarine environments in which to study natural variability and the impacts of climate change without a confounding human impact signal (either directly or as a consequence of catchment land use and management).

The aim of this study was to investigate human impacts on Lake King, Gippsland Lakes, southeast Australia during the last 100+ years and to evaluate the value of a palaeoecological approach to developing better southeast Australian coastal management plans in the future. Specific aims were to establish baseline conditions, determine the impact of human activities including the construction of a permanent entrance to the sea, and to describe the nature and direction of environmental change. This was achieved by applying diatom-phosphate and diatom-salinity transfer functions, based on data from 53 sites in 14 southeast Australian coastal lakes and lagoons, to reconstruct past nutrient conditions using sub fossil diatom assemblages in a sediment core from Lake King. Further evidence of changes in the lake's nutrient status, and organic and inorganic inputs was derived from analyses of total sediment carbon, nitrogen and sulphur, chlorophyll *a* and particle size. The intention is that this study will contribute data that will substantially assist the development of future management strategies to conserve the water quality of the lake and its catchment, and provide a stimulus for future palaeoecological work in Australia.

Site description

Lake King is one of three interconnected lakes known as the Gippsland Lakes in the southeast corner of mainland Australia (Fig. 1). It is the largest estuarine system in Australia, covers 340 km^2 and has a catchment area greater than 20,000 km^2. It is a Ramsar listed site.

Major environmental issues facing the Gippsland Lakes include declining water quality, high nutrient concentrations (from direct and diffuse sources), algal blooms, declining freshwater macrophyte communities (particularly freshwater marshes), shoreline erosion, reduced suitable habitat for waterbirds, stratification and anoxic bottom waters, and introduced exotic plants and animals (Webster et al. 2001; Winstanley 1995). An artificial channel between Lake King and the sea was constructed in 1889 to aid transport in the area (Fig. 1c). Subsequently, the salinity of the lakes has increased and they regularly experience stratification (Bird 1993; Winstanley 1995). Of all the Gippsland Lakes, Lake King has been the most directly affected by the permanent entrance. It experiences the most prolonged periods of stratification, algal blooms and receives major nutrient inputs from three large rivers.

Materials and methods

Sampling methods

Diatom-phosphate and diatom-salinity transfer functions were developed from reference data collected at 53 sites in southeast Australian coastal lakes and lagoons. The calibration set consisted of 41 sites designed to capture a large gradient in nutrient status from within 14 coastal lakes and lagoons (Fig. 1). In addition, a 12 site transect of sediment and water samples was conducted across Lake King to capture spatial variation in nutrient concentrations in the lake associated with marine, riverine and point source inputs from the catchment.

Sites were visited twice during the period of data collection (August 2004 and February 2005) in order to capture some of the seasonal variation in limnology. At each site, a Horiba U-10 Water Quality Checker was used to measure salinity, temperature, pH, turbidity and dissolved oxygen. Duplicate 10 ml water samples were collected for nutrient analysis. Samples were frozen and analysed for phosphate, nitrate/nitrite and silicate using an Alpkem Autoanalyser (Continuous Flow Analyser) at the CSIRO Marine and Atmospheric Laboratories, Hobart, within 2 months of collection.

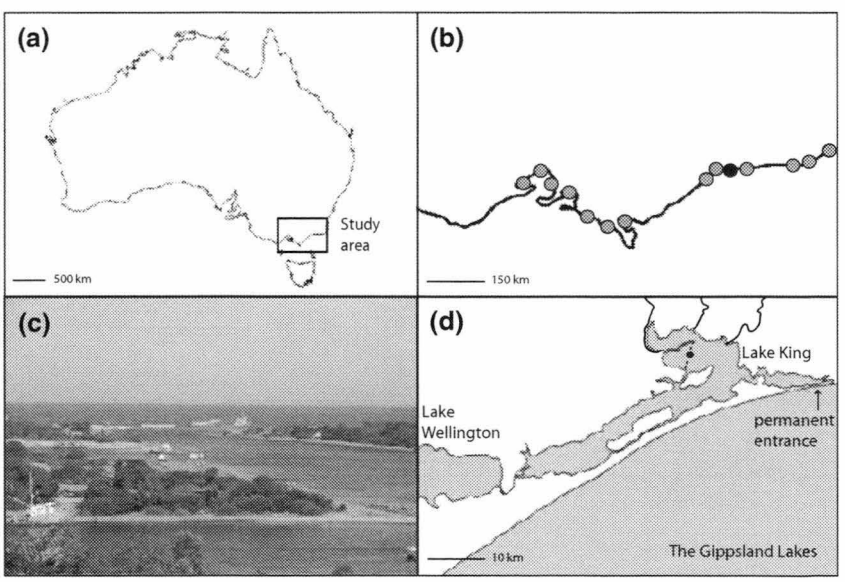


Fig. 1 (**a**) Location of the study area, (**b**) Location of coastal lakes and lagoons in calibration set, with Lake King marked in black, (**c**) Lake King and the permanent entrance, (**d**) Location of core site (*black dot*) and transect (*dashed line*)

Surface sediment samples (top 1 cm) were collected from approximately 1 m water depth using a hand-operated gravity corer.

A 120 cm sediment core was collected from Lake King using a gravity corer (Fig. 1) from a depth of 7 m. The core was sectioned at 0.5 cm intervals from 0 to 50 cm and 1 cm intervals from 50 to 120 cm. The sediment core was analysed for diatoms and chlorophyll *a* at every interval, and particle size, total carbon, nitrogen and sulphur contents at 5 cm intervals. In future studies we recommend that multiple cores are collected and analysed, but this was beyond the scope of the present study.

Laboratory methods

Diatom samples were prepared following standard methods (Battarbee et al. 2001). At least 400 frustules per sample were counted using oil immersion at 1,000 × magnification on a light microscope. The relative abundance of all species (including unidentified forms) was recorded as a percentage of the total number of frustules (Battarbee et al. 2001). Taxonomy was principally based on Australian taxonomic references (i.e. Hodgson et al. 1997; John 1983; Sonneman et al. 2000) and datasets (i.e. Hodgson et al. 1996; Saunders et al. 2007; Taffs 2005) with additional reference to cosmopolitan floras (e.g. Witkowski et al. 2000).

Chlorophyll *a* was extracted in 10 ml of methanol and measured at 440 nm on a Turner Designs 10AU Fluorometer using the acidification method (Holm-Hansen et al. 1965). Sedimentary chlorophyll *a* data were expressed relative to total organic carbon content (TOC), which was determined by loss on ignition (Dean 1974). Both of these analyses were undertaken at the University of Tasmania, Hobart.

Particle size was measured at 5 cm intervals using a Malvern Mastersizer S Laser Particle Size Analyser. Each wet bulk sample was dispersed in water and pumped through a measurement chamber in the laser particle analyser. The particle size distribution of solids with a diameter in the range 0.05–880 μm was determined. Total sedimentary carbon, nitrogen and sulphur were also measured at 5 cm intervals using a LECO CNS 2000 analyser. These analyses were undertaken at the Australian Nuclear Science and Technology Organisation (ANSTO), Sydney.

Sediment chronology

A sediment chronology was established using the ^{210}Pb dating technique (Goldberg 1963; Appleby and Oldfield 1978; Robbins 1978). Unsupported ^{210}Pb activities were measured in bulk sediment samples at the ANSTO Institute for Environmental Research following methods described by McMinn et al. (1997) and Harrison et al. (2003). The unsupported ^{210}Pb activities were modeled using both the Constant Initial Concentration (CIC) (Robbins 1978) and the Constant Rate of Supply (CRS) (Appleby and Oldfield 1978) models. The CIC model assumes that the supply of ^{210}Pb to the system varies directly in proportion to the sedimentation rate, implying the sediment profile exhibits an exponential decrease in unsupported ^{210}Pb (Gelen et al. 2003; Appleby 2001). This model assumes the majority of ^{210}Pb enters the system via river and catchment inputs rather than by atmospheric deposition, which is characteristic of sites with large catchments and river inputs (Appleby and Oldfield 1992). For these reasons the CIC model was selected for age and mass accumulation rate calculations at this site.

Statistical analyses

The distribution of each environmental variable was checked for skewness and $\log_{(x+1)}$ transformed where necessary (i.e. nutrients and turbidity were transformed). Detrended Correspondence Analysis (DCA) with detrending by segments and downweighting of rare species on the species data (untransformed) was used to establish whether species distribution was unimodal or linear. As gradient lengths were > 2 standard deviation units, unimodal ordination techniques were used. Species data were $\log_{(x+1)}$ transformed for subsequent statistical analyses and transfer function development.

Canonical Correspondence Analysis (CCA) with forward selection and Monte Carlo permutation tests (999 permutations on the reduced model) and variance partitioning were used to identify which environmental variables accounted for independent, statistically significant variations in the diatom data. These analyses showed that phosphate and salinity explained the most variation in the diatom assemblage data. All ordinations were performed using

CANOCO 4.5 for Windows (ter Braak and Smilauer 2002) and R (R Development Core Team 2006).

Transfer functions were developed using simple weighted averaging (WA) with inverse and classical deshrinking, and with/without tolerance downweighting. Weighted averaging partial least squares (WAPLS) were also used to determine which model led to the best performing transfer functions. Performance was assessed using leave-one-out cross validation (i.e. jackknifing). The transfer functions for phosphate and salinity with the best correlation (r^2), best predicted correlation (r^2_{jack}), lowest root mean squared error (RMSE), and lowest root mean squared error of prediction ($RMSE_p$) were identified and used. All transfer functions were developed using C2 version 1.4 (Juggins 2003). Water quality monitoring undertaken by the Victorian Environment Protection Agency from 1986 to 2003 was used to investigate recent trends in phosphate and salinity in surface waters and to compare with diatom-inferred phosphate and salinity.

Results

Calibration set

The environmental data for the calibration set are summarised in Table 1. Salinities at the sampling sites spanned a wide salinity gradient ranging from near freshwater (0.8 ppt) to hypersaline (40 ppt). Nutrient concentrations ranged from oligotrophic to eutrophic: phosphate 0–1,077 µg/l (mean 148 µg/l), nitrate/nitrite 0–5,368 µg/l (mean 489 µg/l), silicate 55–1,291 µg/l (mean 367 µg/l). Temperatures in the dataset ranged from 9.6 to 19.2°C (mean 16.2°C) and pH ranged from circumneutral to alkaline: 7.46–8.46 (mean 7.94). Turbidity ranged from 0 to 140 NTU (mean 17 NTU) and dissolved oxygen ranged from very low to high (0.61–18.9 mg/l, mean 4.99 mg/l).

In total, 371 diatom taxa were identified in the calibration set, however nearly half (i.e. 163 taxa) of these occurred with a maximum relative abundance of less than 1%. Only those species occurring ≥ 1% in ≥2 samples were retained in the statistical analyses. This resulted in 157 taxa, which represent 74–99% (mean 92%) of the total diatom counts in the calibration set samples.

Lake King sediment core

Core stratigraphy

The core consisted of dark grey-black, fine-grained sediment with occasional plant macrofossils. Sediment composition was principally (~80%) mud (2–63 µm particles) (Fig. 2). Prior to the permanent entrance being constructed, the percentage of clay and mud remained relatively stable, while two main peaks (up to 10%) in sand occurred. Coinciding with the permanent entrance construction there was a peak in clay (to 25%) followed by sand (to 12%). From c. 1920, the proportion of sand remained relatively stable until a peak of 12% at the top of the core, while the proportion of mud increased from c. 1915 onwards and clay particles decreased (Fig. 2).

Total sulphur varied from 2.6% to 3% prior to the construction of the permanent entrance and was higher during this time than any period since. Both total carbon and total nitrogen were higher prior to construction of the permanent entrance. Total nitrogen recorded two main peaks c. 1920 and 1960, and both increased from c. 1990 to 2005. The total carbon to total nitrogen (C:N) ratio of the sediment indicated that organic matter in the lake was principally derived from terrestrial rather than marine sources. There was a large peak in C:N during the early 1900s, rising to 47.9, indicating large amounts of terrestrial inputs at this time (Fig. 2).

Table 1 Summarised environmental data

	Silicate (µg/l)	Phosphate (µg/l)	Nitrate/nitrite (µg/l)	Salinity (ppt)	Temperature (°C)	pH	Turbidity (NTU)	DO (mg/l)
Mean	396.6	148.4	488.6	27 7	16.2	7.94	17	4.99
Median	282.3	41.9	15.7	31.1	16 4	7.96	6	4.50
Min	55.3	0.0	0 0	0.8	9.6	7.46	0	0.61
Max	1291.0	1077.4	5367 7	40.0	19.2	8.46	140	18.90

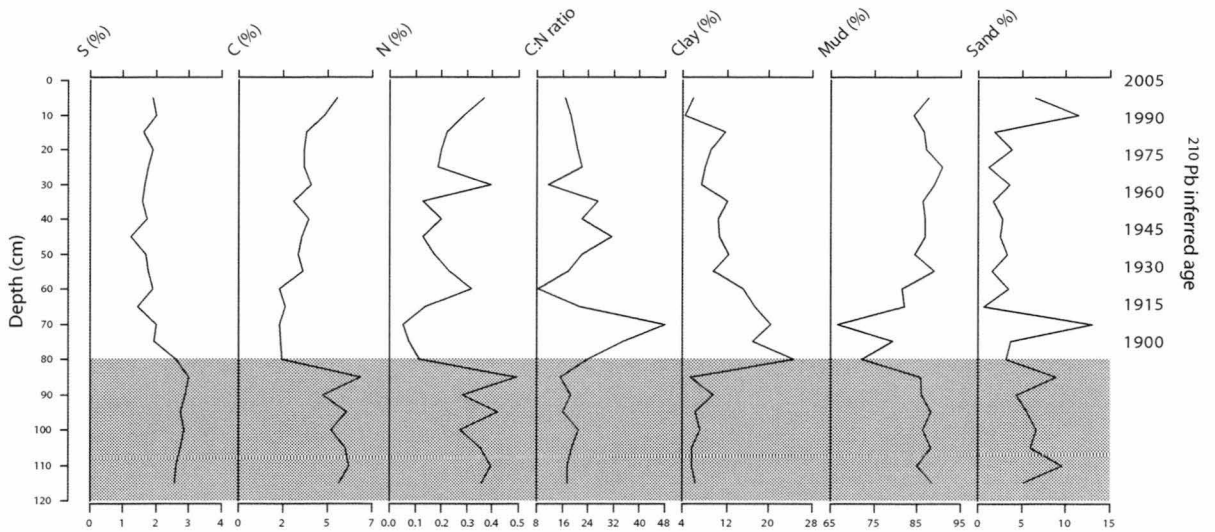


Fig. 2 Total sediment sulphur (S), carbon (C) and nitrogen (N) contents, C:N ratio and particle size (clay < 2 μm, mud 2–63 μm, sand > 63 μm) in the Lake King sediment core. Pre-permanent entrance period indicated by grey shading

Core chronology

The ^{210}Pb profile did not indicate significant mixing of the sediment and the CIC model inferred a sedimentation rate of 0.74 cm/yr (0.28 ± 0.03 g/cm^2/y) to 60 cm (Fig. 3). Below 60 cm ^{210}Pb activities were both low in activity and constant to the base of the core. The data points below 60 cm were not used in the sedimentation rate calculations. However, major changes in the diatom assemblages and sedimentary carbon, nitrogen and sulphur contents occurred at 80 cm, which we interpret as marking the construction of the permanent entrance. Extrapolating a sedimentation rate of 0.74 cm/yr to 80 cm also indicates that 80 cm corresponds to c. 1890. The last 40 cm, while not possible to date with accuracy, provide a good record of the pre-permanent entrance (i.e. pre 1889) state of Lake King.

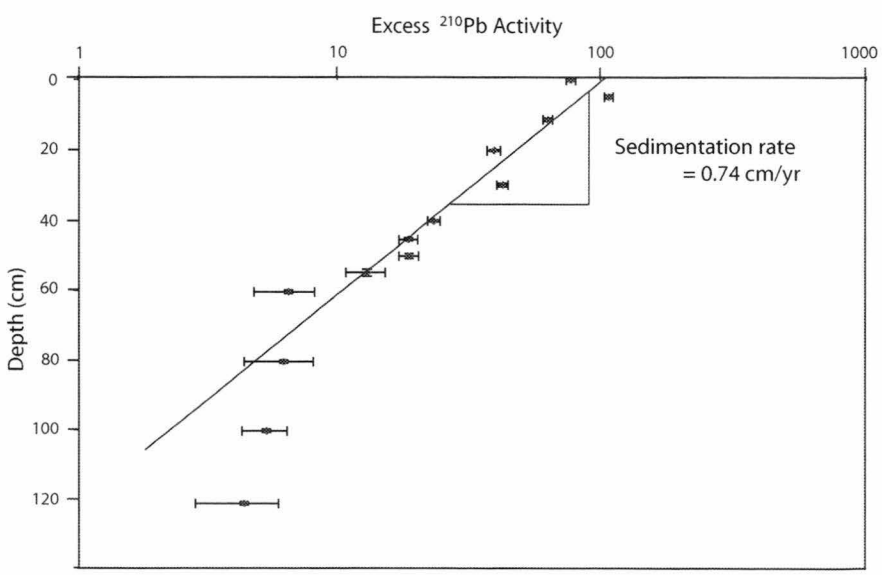


Fig. 3 Unsupported ^{210}Pb activity in the Lake King sediment core, indicating a sedimentation rate of 0.74 cm/yr. Below 60 cm activities were too low to be able to date with accuracy

Diatoms

A total of 201 diatom taxa were identified in the sediment core. Of these, 122 occurred with a relative abundance of ≥1% in ≥2 samples. There were 17 common taxa, occurring with a relative abundance ≥5% in ≥2 samples, and two of these (*Cyclotella choctawhatceeana* and *Cyclotella striata*) occurred in 58% of samples with ≥5% relative abundance (Fig. 4, Table 2).

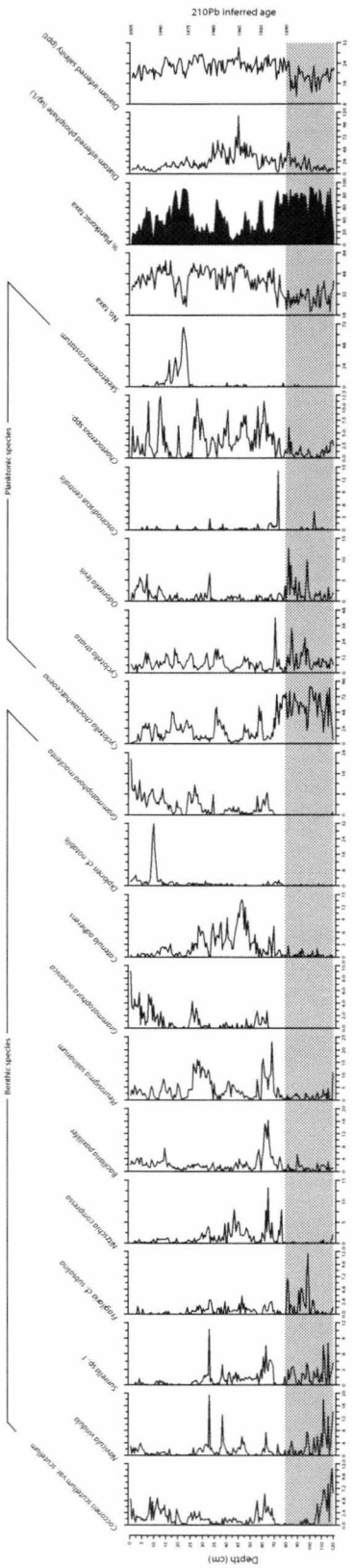
Below 80 cm, the core was dominated by peaks (in relative abundance) of planktonic *Cyclotella choctawhatceeana* (c. 70%) and *Cyclotella striata* (c. 12 %), together with benthic diatoms *Cocconeis scutellum* var. *scutellum* (max. 10%), *Navicula viridula* (max. 18%), and *Surirella* sp. 1 (max. 8%) between 110 and 120 cm and *Fragilaria* cf. *subsalina* (max. 12%) from 100 cm (Fig. 4).

Between the construction of the permanent entrance in 1889 and the 1920s, the relative abundance of *Bacillaria paxillifer*, *Nitzschia compressa* and *Pleurosigma salinarium* increased. From the 1920s to the mid 20th century there were increases in the relative abundance of benthic *Grammatophora oceanica* and *Catenula adherens* and planktonic *Chaetoceros* spp. (Fig. 4).

During the mid 20th century, *Grammatophora macilenta* increased in relative abundance to >8%, dominating the most recent sediments. Additionally, the upper part of the core was characterised by a virtual absence of *Fragilaria* cf. *subsalina*, *Nitzschia compressa* and *Coscinodiscus centralis*. *Skeletonema costatum* had a broad peak in the 1970s before disappearing in the most recent sediments. There was a large increase in the relative abundance of *Diploneis* cf. *notabilis* in the early 1990s.

Both *Chaetoceros* spp. and *Skeletonema costatum* are lightly silicified taxa that easily break down and dissolve under oxic conditions and are often not well preserved in coastal sediments (MOLTEN 2004). Changes between oxic and anoxic conditions in the sediment may affect this and their representation in fossil assemblages.

The number of taxa found in each segment of the core was highest during the early-mid 20th century and declined from 1980 to 2005. The number of taxa was closely linked to the proportion of planktonic taxa as these species commonly dominated the Lake King diatom assemblage. The proportion of planktonic species was closely tied to the proportion of



◀**Fig. 4** Stratigraphy of the common diatom taxa (i.e. species occurring ≥5% ≥2 samples) in the Lake King sediment core (all species are presented as % relative abundance). The number of taxa per core sample (No. taxa), % planktonic taxa and diatom-inferred phosphate and salinity are also illustrated

Cyclotella choctawhatceeana throughout the core and is a major factor driving the percent relative abundance of all planktonic diatoms. While the proportion of this taxon remained important in more recent sediments, *Chaetoceros* spp and *Skeletonema costatum* were responsible for the peaks in planktonic taxa during the 20th century. In the 1980s, a period of low numbers of taxa is due to the dominance of *Skeletonema costatum* (Fig. 4).

Phosphate and salinity reconstructions

Tests using WA (with and without tolerance down-weighting) and WAPLS indicated that WAPLS 2 components resulted in the best performing phosphate transfer function (based on r^2, r^2_{jack}, RMSE, $RMSE_p$ and max. bias, Table 3, Fig. 5), while WA (with classical deshrinking) resulted in the best performing salinity transfer function (Table 4, Fig. 6).

A degree of autocorrelation (Telford et al. 2005) is present in the dataset because it includes a number of very large lagoons (up to 340 km^2) that have been sampled in multiple areas to capture the range of within-lagoon variability in nutrients and salinity, including a number of point source inputs. The standard procedure to address this is leave-one-out cross validation (also known as jackknifing). This was performed on the data to determine its predictive ability (i.e. r^2_{jack}) for inferring absolute phosphate and salinity concentrations. This reduced the predictive ability of the transfer functions (from 0.90 to 0.73 for phosphate and from 0.44 to 0.29 for salinity). While the phosphate transfer function had good predictive ability, this reduced our

Table 2 Common diatom taxa in Lake King sediment core

Species	Code	N_{core} (%)	Max_{core} (%)	N_{ref} (%)	Max_{ref} (%)	P opt (µg/l)	P tol (µg/l)	S opt (ppt)	S tol (ppt)
Benthic species									
Bacillaria paxillifer (O.F. Müller) Hendey 1951	NITscal	94.0	16.2	58.0	5.16	35.6	3.34	25.4	8.54
Catenula adherens (Mereschkowsky) Mereschkowsky 1902–3	AMP1	82.9	13.8	81.1	39.6	51.7	3.42	26.8	7.69
Cocconeis scutellum var. *scutellum* Ehrenberg 1838	COCscu	84.1	11.0	79.1	5.50	38.8	5.56	27.2	8.58
Diploneis cf. *notabilis* (Greville) Cleve	DIPnot3	63.5	31.6	not in calibration dataset					
Fragillaria cf. *subsalina* (Grunow) Lange-Bertalot 1991	FRA8	58.8	11.6	5.71	2.79	95.6	1.62	31.6	6.35
Grammatophora macilenta W. Smith 1856	GRAmac	91.2	21.5	2.80	3.78	24.0	3.53	27.5	6.32
Grammatophora oceanica Ehrenberg 1841	GRAoce	43.5	9.05	67.9	15.4	21.5	3.83	27.4	6.43
Navicula viridula Bleisch ex Fresenius 1862	NAVvir	84.7	19.6	15.1	1.98	1.18	2.40	20.8	5.63
Nitzschia compressa (Bailey) Boyer 1916	FRAvir	68.8	13.3	15.1	1.27	19 6	1.86	20 9	7.18
Pleurosigma salinarum Grunow	GYRbal1	92.9	23.3	95.3	12.6	16.1	3.05	28.6	5.76
Surirella sp. *1*	CEN13	71.8	10 76	4.20	3.02	8.33	0.01	15.5	5.87
Planktonic species									
Chaetocerous spp.	SPO2	89.0	12.3	not in calibration dataset					
Cyclotella choctawhatceaena Prasad 1990	CYCstr	99 4	87.3	37.7	12.8	22.7	1 87	23.4	7.46
Cyclotella striata (Kützing) Grunow 1880	CYCstr3	99.4	42.3	28.3	7.30	30 8	4 05	19.23	10.1
Odontella levis Kutzing	CEN6	78.2	12.6	not in calibration dataset					
Skeletonema costatum (Greville) Cleve 1878	UNK215	35.3	69.2	not in calibration dataset					

N_{core}, number of occurrences as % total number of core samples, Max_{core}, maximum relative abundance in core samples; N_{ref}, number of occurrences as % total number of reference dataset samples; Max_{ref} maximum relative abundance in reference dataset samples; P opt, phosphate optimum; P tol, phosphate tolerance; S opt, salinity optimum; S tol, salinity tolerance

Table 3 Diatom-phosphate weighted averaging transfer function results

	r^2	r^2_{jack}	RMSE log µg/l	RMSEp log µg/l
Simple WA				
WA_{Inv}	0.67	0.57	0.49	0.56
WA_{Cla}	0.67	0.58	0.60	0.67
$WA(tol)_{Inv}$	0.73	0.52	0.44	0.62
$WA(tol)_{Cla}$	0.73	0.52	0.51	0.73
WAPLS				
Component 1	0.67	0.57	0.49	0.56
Component 2	0.90	0.73	0.27	0.44
Component 3	0.95	0.77	0.19	0.41
Component 4	0.98	0.76	0.13	0.42
Component 5	0.99	0.74	0.07	0.44

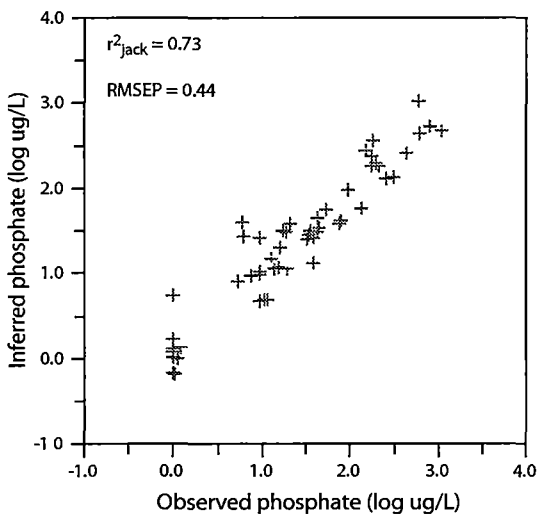


Fig. 5 Performance of the diatom-phosphate WAPLS-2 components transfer function (observed vs. inferred phosphate)

confidence in the absolute reconstructed values for salinity, but not the trends. To address this issue in future studies, and to provide more modern analogues, we recommend that the dataset should be further developed (beyond the scope of the present study) to include more sites from coastal ecosystems around Australia.

Reconstructed phosphate indicated that substantial nutrient changes have occurred since the late 19th century (Fig. 7). Phosphate concentrations steadily rose from <15 µg/l to >50 µg/l by the late 1880s.

Table 4 Diatom-salinity weighted averaging transfer function results

	r^2	r^2_{jack}	RMSE (ppt)	RMSEp (ppt)
Simple WA				
WA_{Inv}	0.44	0.27	6.27	7.24
WA_{Cla}	0.44	0.29	9.44	10.60
$WA(tol)_{Inv}$	0.53	0.21	5.72	7.67
$WA(tol)_{Cla}$	0.53	0.24	7 83	9.88

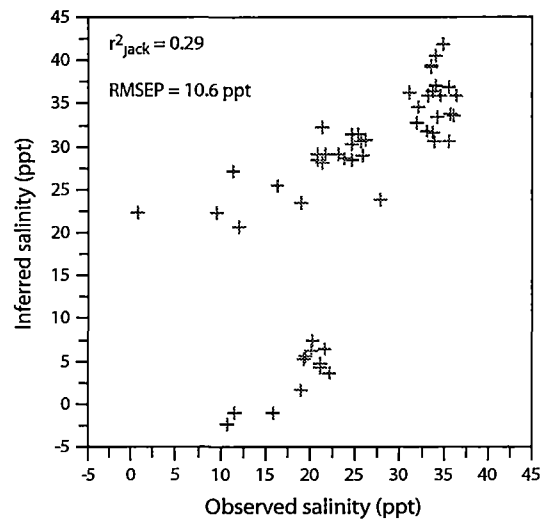


Fig. 6 Performance of the diatom-salinity simple WA transfer function (observed vs inferred salinity)

During the 20th century peaks in phosphate concentration occurred in the 1940s and 1950s up to a maximum of 100 µg/l before declining to below 25 µg/l from c. 1970 to 2005.

While the salinity transfer function performed relatively poorly and cannot be used to provide a quantitative reconstruction, it does show a trend that agrees well with a qualitative assessment of changes in salinity from changes in the diatom assemblages (i.e. brackish vs. marine species). Together these indicate lower salinity prior to the permanent entrance, higher salinity for most of the 20th century and an overall decrease since from 1980–2005 (Fig. 7). This gives us some confidence that the salinity transfer function could be improved to provide quantitative reconstructions by an extended sampling campaign along a longer salinity gradient.

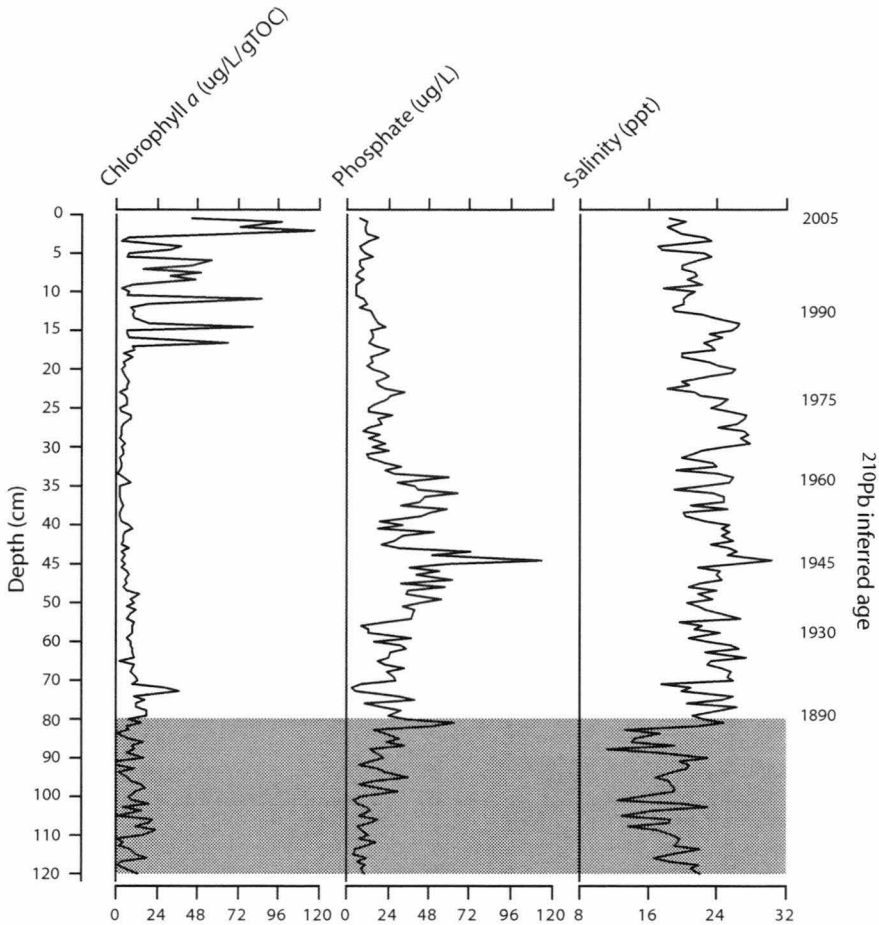


Fig. 7 Measured sedimentary chlorophyll *a* and diatom-inferred phosphate and salinity in the Lake King sediment core. Pre-permanent entrance period indicated by grey shading

Monitoring versus palaeo data for Lake King from 1986-present

Monthly measurements (summarised as annual averages of measurements made in surface waters) of phosphate and salinity in Lake King have been made by the Victorian Environment Protection Agency from 1986 to present (Fig. 8). High phosphate values were recorded in 1988 (27.5 μg/l) and from 1999 to 2001 (max. 18 μg/l). Salinity was high in 1988 (22.5 ppt), 1994 (21 ppt) and >20 ppt since 1997. Low salinity values were measured in 1993 (13.5 ppt) and 1996 (14 ppt, Fig. 8).

Diatom-inferred phosphate and salinity trends for the same period represent values integrated over a period of approximately 8 months (i.e. sample interval of 0.5 cm/^{210}Pb inferred accumulation rate of 0.74 × 12 months = 8.1) and thus constitute data from which longer-term trends can be identified.

Peaks in reconstructed and measured phosphate differ, however trends are similar: higher values for both occur c. 1987 to 1989, followed by a decrease, then rise c. 1998. Measured phosphate continued to rise until 2001, however reconstructed phosphate decreased before rising to a peak c. 2001. Actual values of reconstructed and measured phosphate for the two main high periods of phosphate (i.e. c. 1988 and 2001) are similar (i.e. ~20 μg/l). Both indicated a decrease from 2002 to 2003. Measured and inferred salinity follow similar trends from 1986 to 1999. Both recorded higher salinity c. 1988 before decreasing c. 1989 and again c. 1993. From 1999 to 2003 they showed opposite trends (Fig. 8).

Chlorophyll a

Sedimentary chlorophyll *a* content varied throughout the core. Prior to the permanent entrance (i.e. pre 1889, which corresponds to 80–120 cm), chlorophyll *a* ranged from 0 to 23.0 μg/l/gTOC, with a mean of

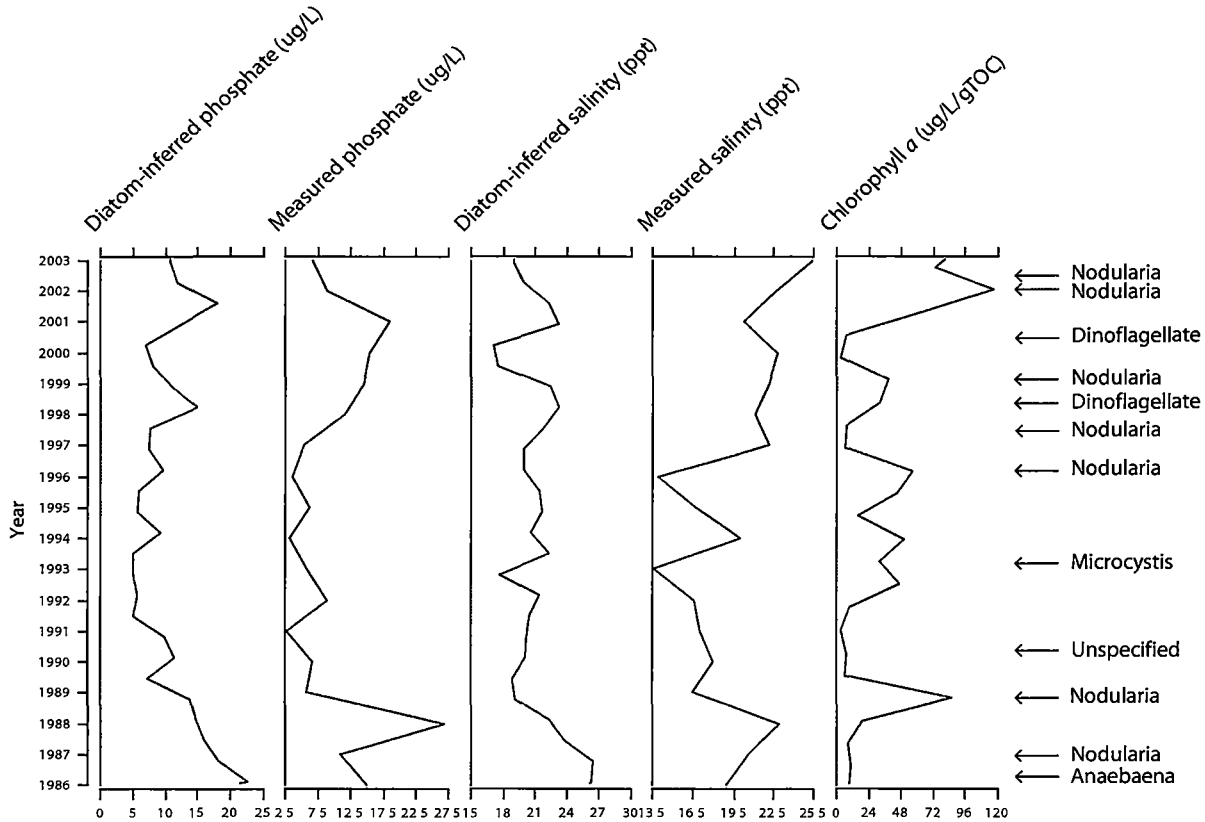


Fig. 8 Diatom-inferred phosphate and salinity and measured phosphate and salinity from monitoring data (1986–2003). Measured sedimentary chlorophyll *a* and known algal bloom occurrence are also illustrated

9.36 μg/l/gTOC. From 1889 to 1980 chlorophyll *a* ranged from 1.42 to 37.25 μg/l/gTOC with a mean of 7.03 μg/l/gTOC. From 1980 to 2005, chlorophyll *a* ranged from 3.46 to 649.3 μg/l/gTOC with a mean of 51.24 μg/l/gTOC with nine main peaks (Fig. 7).

Discussion

Establishing baseline conditions

Prior to widespread European settlement and the opening of the permanent entrance, the diatom flora indicates that Lake King was a brackish water environment. The diatom assemblage was dominated by brackish *Cyclotella choctawhatceeana* and *C. striata*. The presence of *Cocconeis scutellum* var. *scutellum* at the base of the core also indicates that seagrass or other macrophyte cover was present before construction of the permanent entrance (Fig. 4). The assemblage also included some marine species that are likely to have been present as a result of the natural opening of the lake to the sea, which intermittently occurred when the sand bar was breached (Bird 1965).

Relatively high sulphur content in the sediment indicates that at least some periods of hypoxia may have occurred prior to the construction of the permanent entrance (Fig. 2). The presence of well-preserved, small sized taxa also suggests hypoxic conditions (Ellegaard et al. 2006) and possible periods of stratification. The cycling between benthic and planktonic species at the base of the core (Fig. 4) also suggests periods of stratification and probable algal blooms, indicating that both were likely to have been features of the Lake King environment, a finding also supported by 19th century historical records (Stephens et al. 2004).

The increases in phosphate that occurred before the construction of the permanent entrance were preceded by peaks in *Cyclotella choctawhatceeana*. This is similar to findings by Weckström and Juggins (2006)

from sites around the Baltic Sea where *Cyclotella choctawhatceeana* occurred in anthropogenically impacted sites, but did not cope with subsequent high nutrient environments. Increases in phosphorus have also been found in Danish lakes and attributed to increased soil erosion and manuring of agricultural land (Bradshaw et al. 2006). This explanation may also apply to Lake King. Studies on the Murray-Darling basin (Australia) have shown no trace of fertiliser derived phosphorus, but strong evidence of natural phosphorus entering the river due to accelerated erosion of subsoils and river banks (Davis and Koop 2006). The extensive land clearing of the 19th century and subsequent accelerated erosion, together with the introduction of European-style agriculture during the 1800s, may similarly have contributed to rising phosphate concentrations in Lake King.

The impact of constructing a permanent entrance

Large changes in the ecology of Lake King occurred with the construction of the permanent entrance. Brackish planktonic species *Cyclotella choctawhatceeana* and *C. striata* dominated the planktonic taxa in the core. *Cyclotella choctawhatceeana* decreased after the construction of the permanent entrance and *Chaetoceros* spp. (a marine planktonic species) increased, however *C. choctawhatceeana* still remained a dominant component of the total sum of planktonic species, even with a clear increase in marine taxa. A similar trend was observed by McMinn et al. (2004) in the Hawksebury River, eastern Australia, where a reduction in freshwater inflow resulted in a reduction in the abundance of *Cyclotella* species from c. 1800 onwards, and an increase in marine planktonic taxa including *Chaetoceros* and *Thalassiosira* species. The benthic diatom flora also records the increase in salinity with the establishment of marine taxa including *Pleurosigma salinarium*, *Grammatophora oceanica* and *Catenula adherens* (c.f. Witkowski et al. 2000).

The nature and direction of environmental change in the 20th century

During the 20th century two main peaks in phosphate occurred (1940s and 1950s). The second peak corresponded with the introduction of artificial fertilisers into Australian agriculture (in 1951, Brodie 1995). A smaller third peak in the 1970s coincided with a peak in *Skeletonema costatum*, which has been identified as an indicator species in other high nutrient environments (Weckström 2006). *Skeletonema costatum* is not often well preserved in coastal sediments, however it became a dominant feature of the diatom assemblage in the 1970s. *Skeletonema costatum* is absent in the calibration set (Table 2), which suggests that the small increase in reconstructed phosphate at the time *Skeletonema costatum* peaks underestimates actual phosphate concentrations during this time. This coincided with a reported shift in the ecology of upstream Lake Wellington, which, after a major drought in 1967/68, shifted from a macrophyte to phytoplankton dominated system (Webster and Harris 2004). It is possible that other areas of the lakes followed a similar trend (S. Roberts, personal communication, 5 November 2006). Macrophytes are thought to keep nutrients sequestered in the sediment nutrient cycle and modulate nutrient pulses by drawing down water column nutrients (Harris 1999). A shift from macrophyte to phytoplankton dominance may have resulted in more nutrients being available from the sediment (McGlathery et al. 2001).

In recent years (i.e. from 1975 to present) phosphate and salinity generally declined, while biological productivity (as indicated by sedimentary chlorophyll *a*) increased, experiencing at least nine major peaks. It is thought that algal blooms naturally occur in Lake King, but that their frequency and biomass have increased in recent years (C. Barry, personal communication, 17 October 2006). The chlorophyll *a* record supports this interpretation and provides an indication of biological production over the last 100+ years (Fig. 7). Biological production was slightly higher prior to the permanent entrance, but large peaks in chlorophyll *a* began to occur only from c. 1980 onwards. The occurrence of algal blooms has been recorded since the late 1970s, and while their timing is related to when they were reported rather than when they began (Stephens et al. 2004), many peaks in chlorophyll *a* recorded in the sediment since the 1980s correspond with known algal bloom events (Fig. 8), although some are reported to have occurred when chlorophyll *a* values are low. The

main peaks in chlorophyll *a* coincide with reported blue-green (*Nodularia spumigena*) algal bloom events (Stephens et al. 2004).

Implications for future management

This study has shown that the Gippsland Lakes have experienced extensive environmental changes since European settlement, in particular since the establishment of the permanent entrance, which caused a shift from a brackish-water to marine diatom flora.

Despite the establishment of the permanent entrance, the diatom assemblages, chlorophyll *a* concentrations and sulphur contents all indicate that stratification and algal blooms are likely to have been a natural feature of Lake King throughout the period represented by the core. This raises some important management implications regarding the environmental objectives of managing Lake King, which are to prevent or reduce algal blooms, as well as the feasibility and cost of various management options. There is substantial debate as to whether, in a modified system such as the Gippsland Lakes, management should aim to return the system to as near as possible to its 'natural' or pre-European state, or whether environmental objectives focussed on meeting stakeholder needs are more appropriate (Webster et al. 2001).

In the case of the Gippsland Lakes, the main management strategy is to reduce nutrient loads and improve water quality. Part of this strategy involves reducing the frequency and severity of algal blooms. However, recent large peaks in chlorophyll *a* do not correspond to high water column phosphate as inferred by the diatoms. Phosphate was much higher during the mid 20th century than in recent years, so the link between nutrients and algal blooms is not well established. This suggests that other factors are involved. To establish baseline conditions, further work is needed to investigate pre-permanent entrance algal blooms in terms of type, frequency and extent, particularly in relation to *Nodularia spumigena*, which is currently the most common blooming algal species. This could be achieved using HPLC analyses of sedimentary blue-green algal carotenoids (e.g. Hodgson et al. 1998).

Value of a palaeoecological approach for coastal ecosystem management

Tackling the increasing problem of declining water quality in coastal waters internationally is an important issue. As urban populations continue to expand, land clearing for agriculture continues and consequently nutrient input from erosion and fertiliser use occurs, this problem will only be exacerbated. Deciding on the appropriate management of coastal lakes, lagoons and estuaries is a difficult task. Successful management, whether the aim is conservation, restoration, or 'sustainable wise-use' requires the identification of baseline conditions, rates and extent of change. Climate variability and predicted climate changes also need to be considered as future changes may mean it is not possible to restore sites to their 'natural' or in the case of Australia, pre-European impact status, particularly at coastal sites where sea level rise is an important management consideration. Attempting to restore and return an ecosystem to what it once was may not be ecologically or economically practical.

Current Australian and New Zealand guidelines for fresh and marine water quality state that defining reference conditions that provide a target for management actions and a meaningful comparison for monitoring programs is necessary (NWQMS 2000). There are guidelines on how to define these reference conditions, however they are based on finding nearby relatively 'undisturbed' sites and using these to determine reference conditions. In many cases there are no nearby sites to the site of interest to be able to do this. In the absence of long term monitoring, a palaeoecological approach offers the only way to determine these reference conditions on a site-by-site basis.

Conclusions

This study is one of the first coastal palaeoecological studies to be conducted in the Southern Hemisphere. The number of palaeoecological studies on southern Australian coastal environments is increasing (e.g. work is currently being undertaken on Lake Alexandrina and the Coorong, South Australia), however ties between a palaeoecological approach and coastal management still need to be developed.

In terms of the future management of Lake King, this study has provided valuable information on the past ecology of the lake, the impact of the permanent entrance, and changes in phosphate and salinity over the last 100+ years, together with evidence that supports the presence of algal blooms throughout the record. Changes in diatom assemblages record a shift from a brackish-water to marine diatom flora since the construction of the permanent entrance. Concentrations in phosphate increased at the same time and experienced major peaks in the 1940s and 1950s to >100 μg/l. Clear increases in chlorophyll *a* have also occurred since the 1980s (to a maximum of 120 μg/l/gTOC), likely associated with an increase in the frequency and intensity of algal blooms. Collectively these data show that the ecology of Lake King is now very different to that present during early European settlement.

We have shown that palaeoecological approaches may provide much of the baseline and background information needed for successful management of coastal ecosystems, and is a potentially valuable tool for coastal environmental managers globally.

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